Title: The Clock Ambiguity and the Emergence of Physical Laws

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Abstract: The â€œclock ambiguityâ€• is a general feature of standard formulations of quantum gravity, as well as a much wider class of theoretical frameworks. The clock ambiguity completely undermines any attempt at uniquely specifying laws of physics at the fundamental level. In this talk I explain in simple terms how the clock ambiguity arises. I then present a number of concrete results which suggest that a statistical approach to physical laws could allow sharp predictions to emerge despite the clock ambiguity. Along the way, I get to ask some interesting questions about what we expect of fundamental laws of physics, and give some surprising answers.

The Clock Ambiguity and the emergence of physical laws

Andreas Albrecht

UC Davis

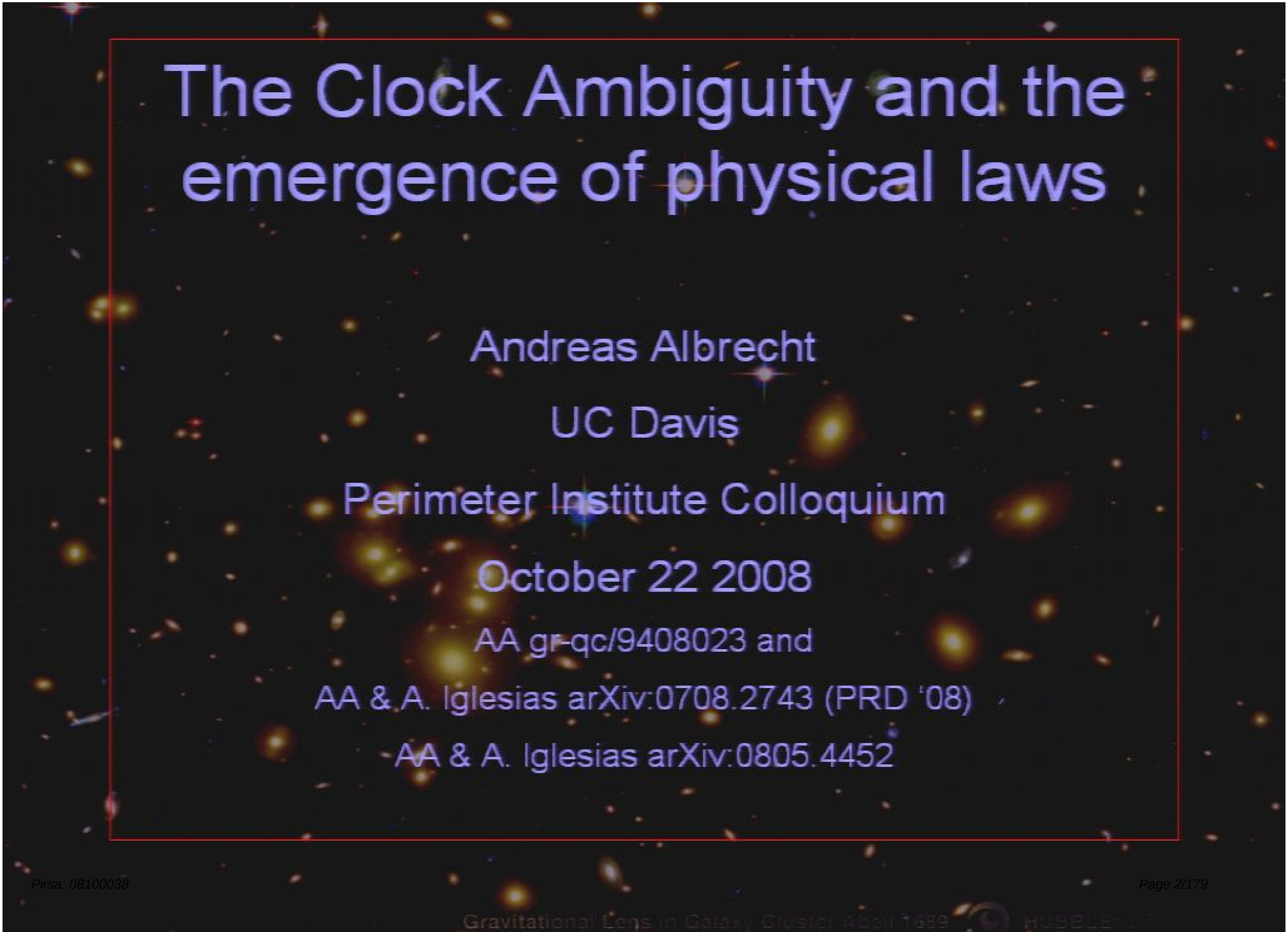
Perimeter Institute Colloquium

October 22 2008

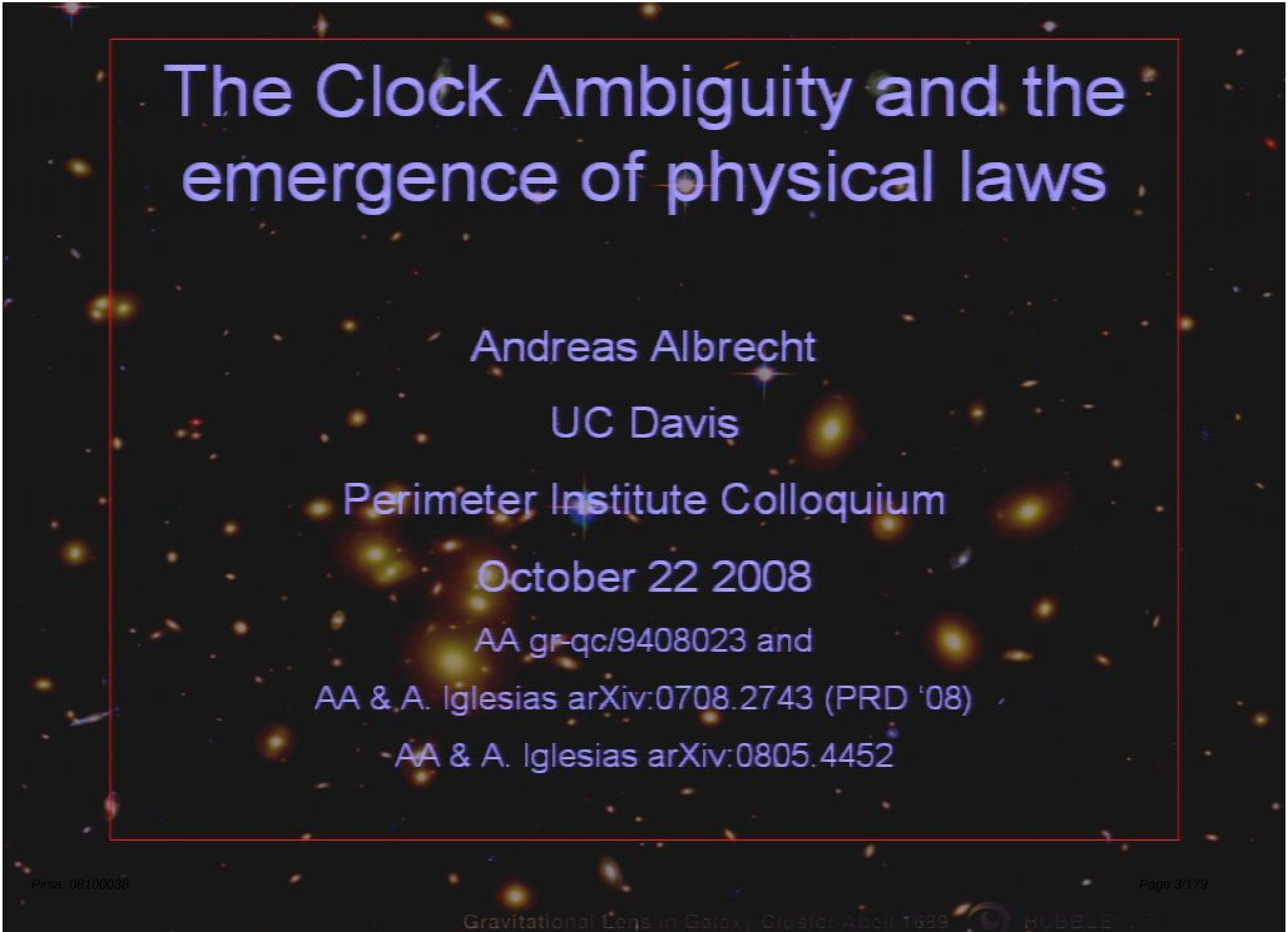
AA gr-qc/9408023 and

AA & A. Iglesias arXiv:0708.2743 (PRD '08)

AA & A. Iglesias arXiv:0805.4452



Gravitational Lens in Galaxy Cluster Abell 1689 HUBBLE



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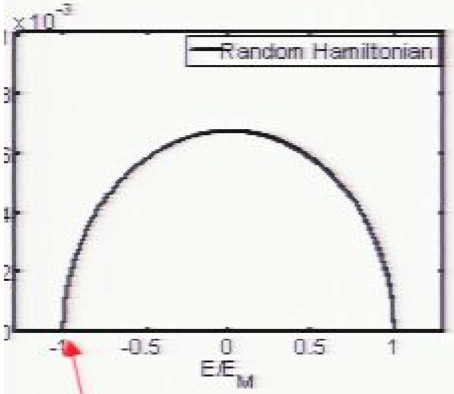
Taylor expand around some energy E_0 and set 0th and 1st order terms equal.



$$\frac{\left(\frac{E_0-E_S}{E_m}\right)^2}{\left(1-\left[\frac{E_0-E_S}{E_M}\right]^2\right)}=\alpha b\left(c\frac{E_0}{\Delta k}\right)^{\alpha}$$

"Energy of the universe"

Huge number

Close to edge of semicircle

Extremely close to unity

k-space lattice gap (2π/box size)

$$\left.\frac{dN}{dE}\right|_R=\left.\frac{dN}{dE}\right|_F$$ at 1st order

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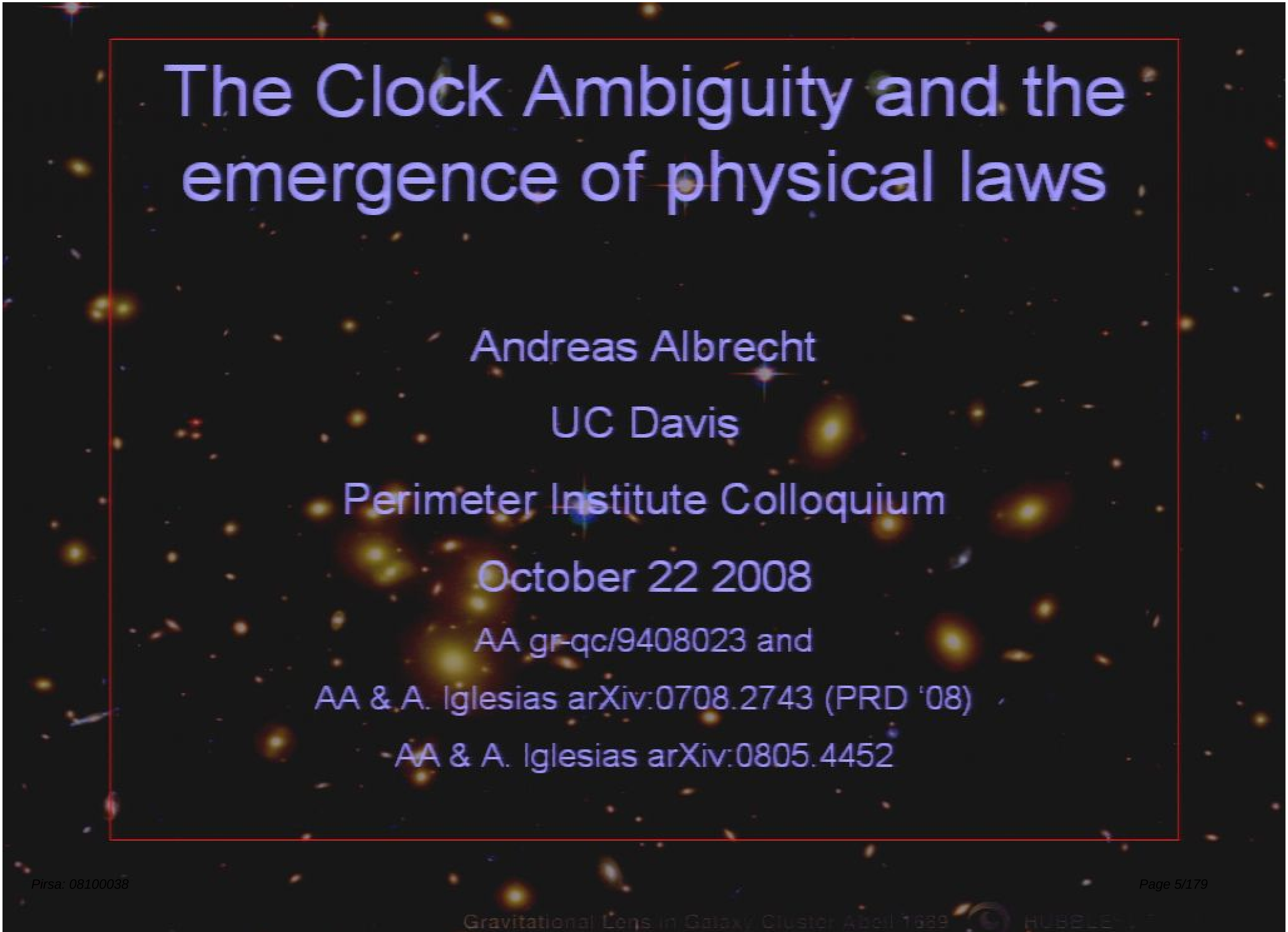

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Questions

1) Should a fundamental theory state the laws of physics explicitly, or draw them at random from a distribution (which is hopefully sharply peaked in some way)?

2) Is field theory + general relativity a valid description of nature at energies below 10^{80} *GeV* (the energy of the observed Universe).

3) Why do I think some aspects of current theoretical physics should be absolute, while I am willing to abandon others in the hopes of achieving a deeper understanding.

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2) Is field theory + general relativity a valid description of nature at energies below 10^{80} *GeV* (the energy of the observed Universe).

3) Why do I think some aspects of current theoretical physics should be absolute, while I am willing to abandon others in the hopes of achieving a deeper understanding.

NB:

- I am asking these questions because I am forced to as I attempt to do quantum cosmology.
- I have some concrete results which I believe are provocative.

Key points

- ➔"Internal time" in quantum gravity leads to total ambiguity about the laws of physics (AA '94) aka "the clock ambiguity" (AA & Iglesias '07, '08). *Specifically, it is impossible to specify the laws of physics in any fundamental way.*

- ➔ Perhaps input assumptions are wrong (for example probability without time)

- ➔ Perhaps we can actually do physics under these conditions

Outline

1) The clock ambiguity
2) How one might do physics despite the clock ambiguity
3) Case study: Field Theory “from” random matrices

- In GR, the full Hamiltonian annihilates the state:

$$H\left|\Psi\right\rangle = 0$$

- due to time reparameterization invariance.
- Many interpret this to mean time emerges by

→ identifying a degree of freedom (or a "subsystem") as the "clock" and

→ looking at correlations between the rest of the universe and the clock.

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→ identifying a degree of freedom (or a "subsystem") as the "clock" and

→ looking at correlations between the rest of the universe and the clock.

Next: Express the above in a finite and discrete space (should give a "good enough" account of real physics)

Consider a state

$$|\Psi\rangle_S$$

In superspace

$$S$$

Identify the clock subspace C with $S = C \otimes R$

"the rest"

Now consider bases

$\{|t_i\rangle_C\}$ spanning C ("eigenstates of the clock operator")

$\{|j\rangle_R\}$ spanning R

The direct products states form a basis for the superspace, so one can expand any state in superspace:

$$\left|\Psi\right\rangle_S = \sum_{ij} \alpha_{ij} \left|t_i\right\rangle_C \left|j\right\rangle_R$$

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Now define

$$\left|\phi(t_i)\right\rangle_R \equiv \sum_j \alpha_{ij} \left|j\right\rangle_R$$

so that

$$\left|\Psi\right\rangle_S = \sum_{ij} \left|t_i\right\rangle_C \left|\phi(t_i)\right\rangle_R$$

In this formalism

$\left|\phi(t_i)\right\rangle_R$ is “the state of the universe at t_i ”

To answer the question “what is the probability of finding the universe in state $|x\rangle$ at time t_3 ?”

Pose a conditional probability question: If the clock is in state $|t_3\rangle$ what the probability of finding “the rest” in state $|x\rangle$?

Answer:

$$\left| \frac{{}_R\langle x|\phi(t_3)\rangle_R}{\sqrt{{}_R\langle \phi(t_3)|\phi(t_3)\rangle_R}} \right|^2$$

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So far I have just given a formal statement of a standard approach

For example, classic papers in quantum cosmology use the cosmic scalefactor "*a*" as the time or "clock" parameter.

(Hartle & Hawking '83, Banks et al '85, Halliwell & Hawking '85, Fischler et al '85)

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Now I will demonstrate how simply by identifying a new clock subsystem C' one can use the original state $|\Psi\rangle_S$ to describe any state evolving according to any Hamiltonian.

$$\left|\Psi\right\rangle_S = \sum_{ij} \alpha_{ij} \left|t_i\right\rangle_C \left|j\right\rangle_R$$

To start with, a different wavefunction evolving according to a different Hamiltonian can correspond to a *different* state in superspace:

$$\left|\Psi'\right\rangle_S = \sum_{ij} \boxed{\beta_{ij}} \left|t_i\right\rangle_C \left|j\right\rangle_R$$

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I will now explicitly construct a new clock-rest split that yields

$$\left|\Psi\right\rangle_S = \sum_{ij} \boxed{\beta_{ij}} \left|t_i\right\rangle_{C'} \left|j\right\rangle_{R'}$$

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Primes here
not here

First, for convenience re-label the tensor product basis states

$$|k\rangle_S \equiv |t_i\rangle_C |j\rangle_R$$

where $k(i,j)$ defines some one-to-one mapping from the finite set of integer pairs $\{(i,j)\}$ to the same number of single integers $\{k\}$

and thus we can re-label the expansion coefficients

$$\alpha_k \equiv \alpha_{i(k),j(k)} \qquad \beta_k \equiv \beta_{i(k),j(k)}$$

where $i(k)$ and $j(k)$ just invert $k(i,j)$

Choose a unitary transform $\mathbf{M}$

so
$$\mathbf{M}\left|\Psi\right\rangle_S = \left|\Psi'\right\rangle_S$$

or
$$\left|\Psi\right\rangle_S = \mathbf{M}^{-1}\left|\Psi'\right\rangle_S$$

Now we have the old state

$$\left|\Psi\right\rangle_S = \sum_k \alpha_k \left|k\right\rangle_S$$

and the state corresponding to the new wavefunction with the new time evolution $$\left|\Psi'\right\rangle_S = \sum_k \beta_k \left|k\right\rangle_S$$

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↑

We can operate on both sides of this with $\mathbf{M}^{-1}$ to get

$$\mathbf{M}^{-1}\left|\Psi'\right\rangle_S = \sum_k \beta_k \mathbf{M}^{-1} \left|k\right\rangle_S$$

or

$$\left|\Psi\right\rangle_S = \sum_k \beta_k \left|k'\right\rangle_S \qquad \text{where} \qquad \left|k'\right\rangle_S \equiv \mathbf{M}^{-1}\left|k\right\rangle_S$$

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where $|k'\rangle_S \equiv \mathbf{M}^{-1}|k\rangle_S$

($\mathbf{M}$ unitary preserves normalized property of bases)

Now use the same function $k(i,j)$ to construct the new clock-rest decomposition:

$$\left|t_{i(k')}\right\rangle_{C'}\left|j(k')\right\rangle_{R'}=\left|k'\right\rangle_{S}$$

so we get

$$\boxed{\left|\Psi\right\rangle_{S}=\sum_{ij}\beta_{ij}\left|t_{i}\right\rangle_{C'}\left|j\right\rangle_{R'}}$$

as promised

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Example:

➔ Build $|\Psi\rangle_S$ out of standard model of electroweak physics (for which a Nobel prize has been awarded) .

➔ A different choice of clock would yield same world with O(3) model of electroweak physics being true (and presumable with a Nobel prize awarded to *its* inventors).

Comments on the clock ambiguity:

➔ No similar issue with lab physics. A cosmological perspective is fundamental to the point.

➔ Most clock choices give "garbage"

➔ No respect for continuum

➔ Well-defined measures & probabilities in superspace (no time) required.

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UPSHOT:
Either some part of the input assumptions are wrong or we must be able to do physics under these conditions (!)

Do we really understand quantum gravity well enough to feel forced to accept the implications of the clock ambiguity?

Comme

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Q: Do we really understand quantum gravity well enough to feel forced to accept the implications of the clock ambiguity?

A: No. But the clock ambiguity is rooted in very basic ingredients:

- Quantum Theory
- Internal time

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For further discussion

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Rest of talk

Similar ideas in the functional formalism:

➔ *General statistics* C. Wetterich Nucl. Phys. B314 (1989), p. 40.

➔ *Geometry from general statistics* C. Wetterich Nucl.Phys.B397:299-338,1993.

See also

➔ Matrix theory

➔ Matrix universality of gauge and gravitational dynamics (L. Smolin)

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3) Case study: Field Theory “from” random matrices

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- Superspace formalism with internal time is fundamental (fundamental language of probability?)
- Quantum Measurements is just

  i) Schrödinger equation plus

  ii) Thermodynaical arrow of time

  → not a separate problem from finding these ingredients

- No *a priori* assumptions about space & gravity (causality etc.)
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The search for “Good Clocks” ➔ successful observers

➔Thrive as tiny subsystems

➔ Learn and predict behavior of surroundings

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“Anthropic”, but not about what it takes for “life to exist” (equally valid for automatic data acquisition)

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➔ Thrive as tiny subsystems ➘

Quasi-separability

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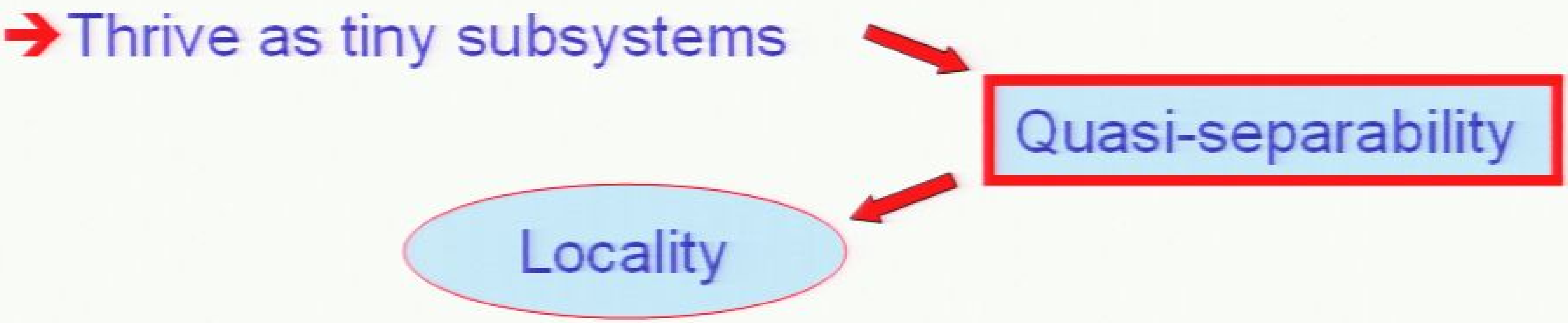

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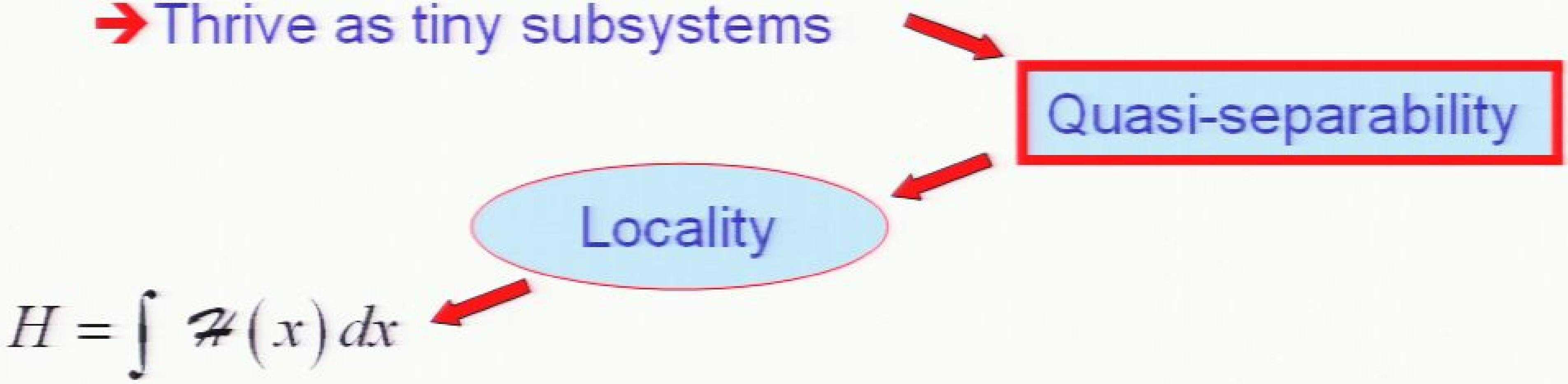

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$$H = \int \mathcal{H}(x)\,dx$$

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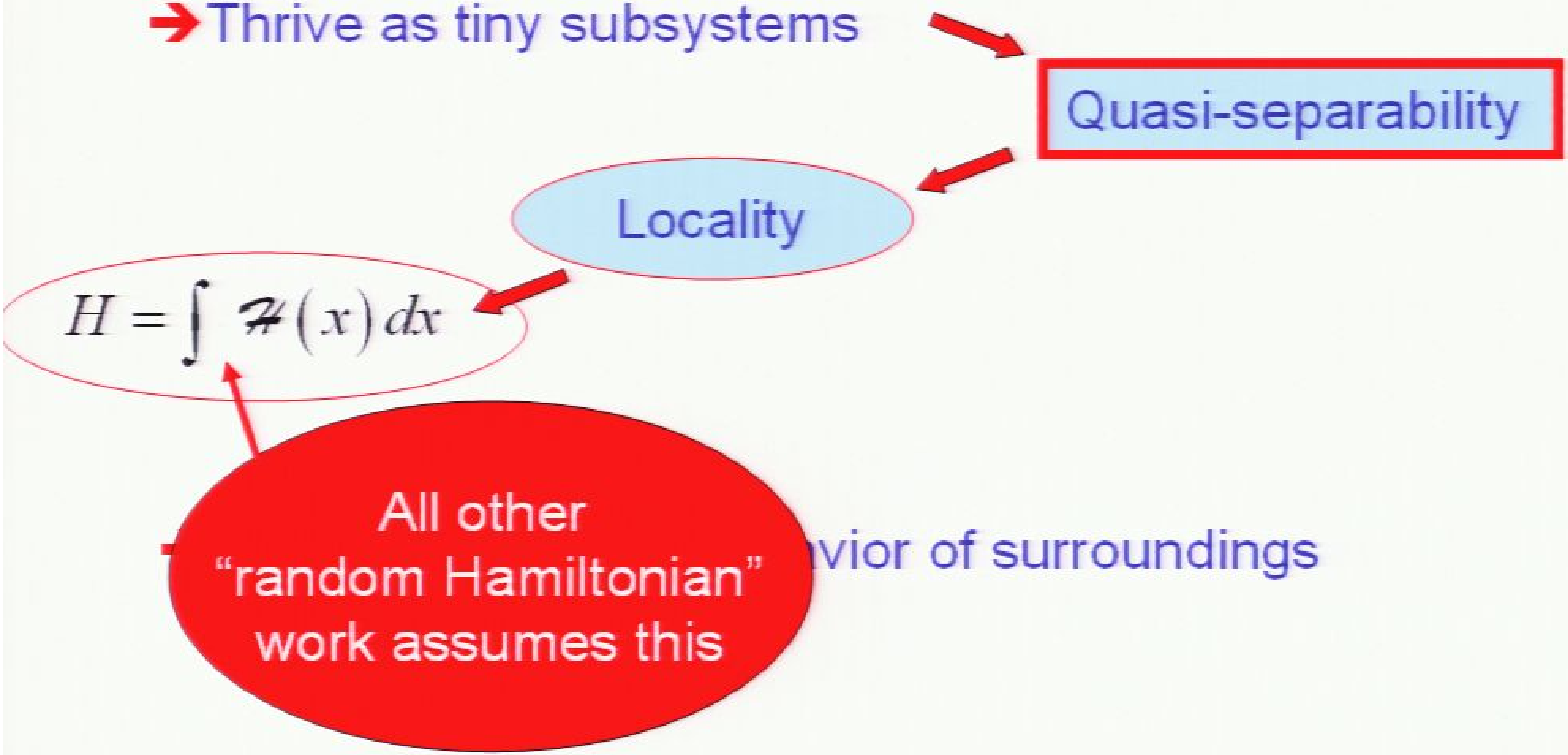

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$$H = \int \mathcal{H}(x)\,dx$$

All other “random Hamiltonian” work assumes this

vior of surroundings

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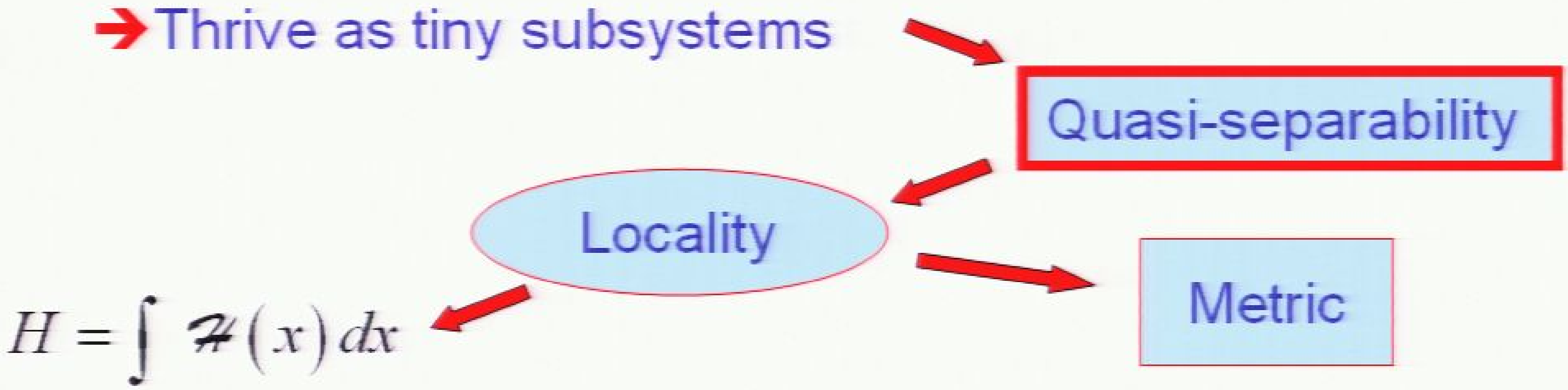


- ➔Thrive as tiny subsystems

Quasi-separability

Locality

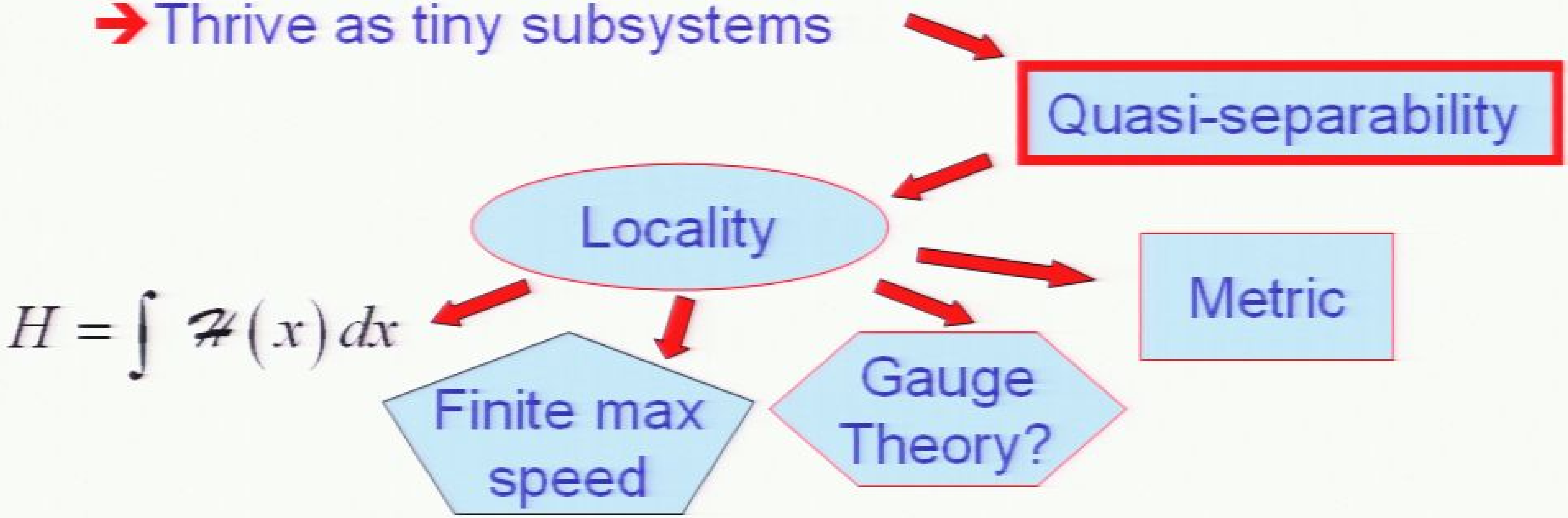
Metric

$$H = \int \mathcal{H}(x)\,dx$$

- ➔ Learn and predict behavior of surroundings

The search for “Good Clocks” ➔ successful observers

➔ Thrive as tiny subsystems



Quasi-separability

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Finite max speed

Gauge Theory?

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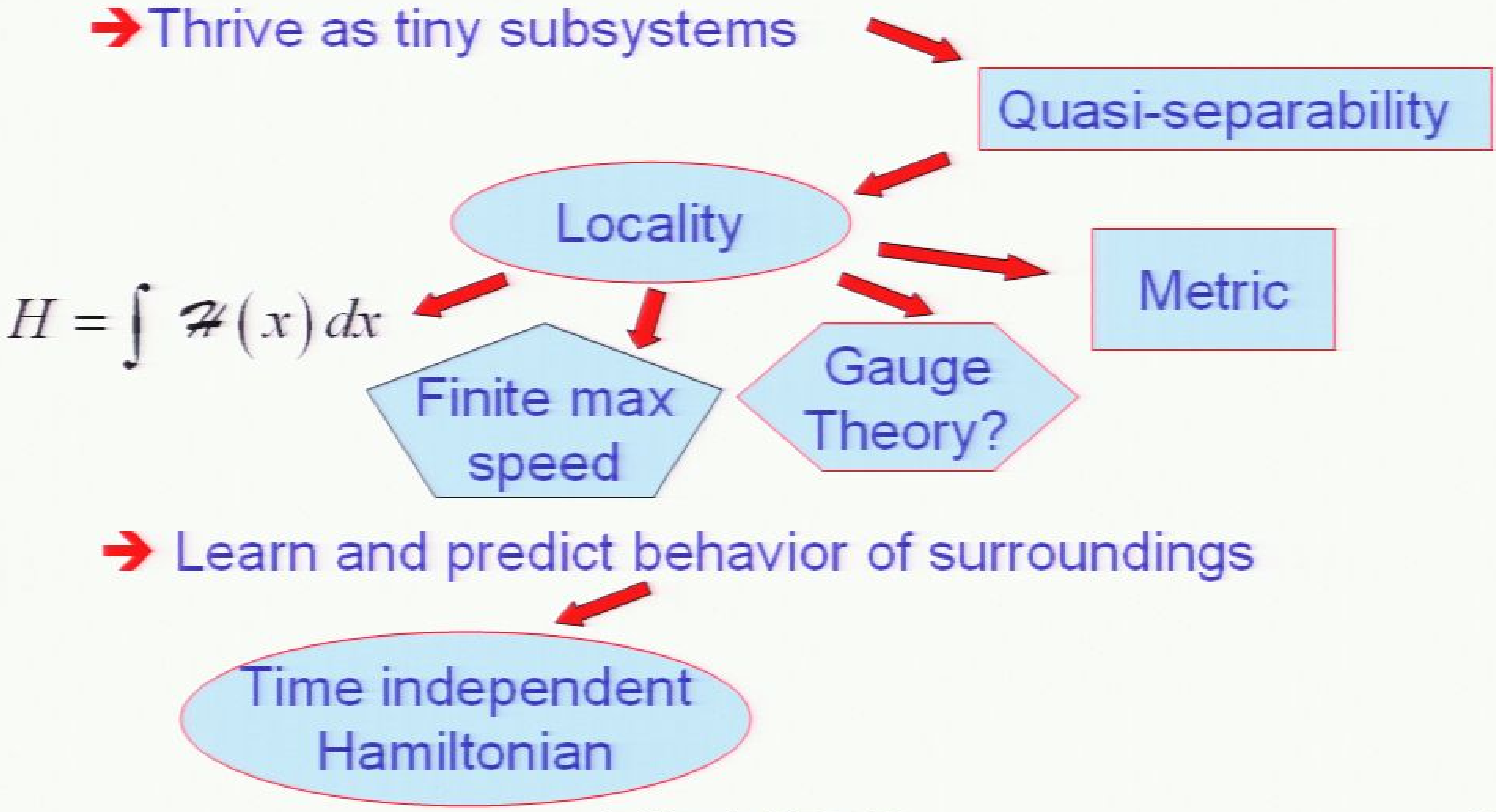

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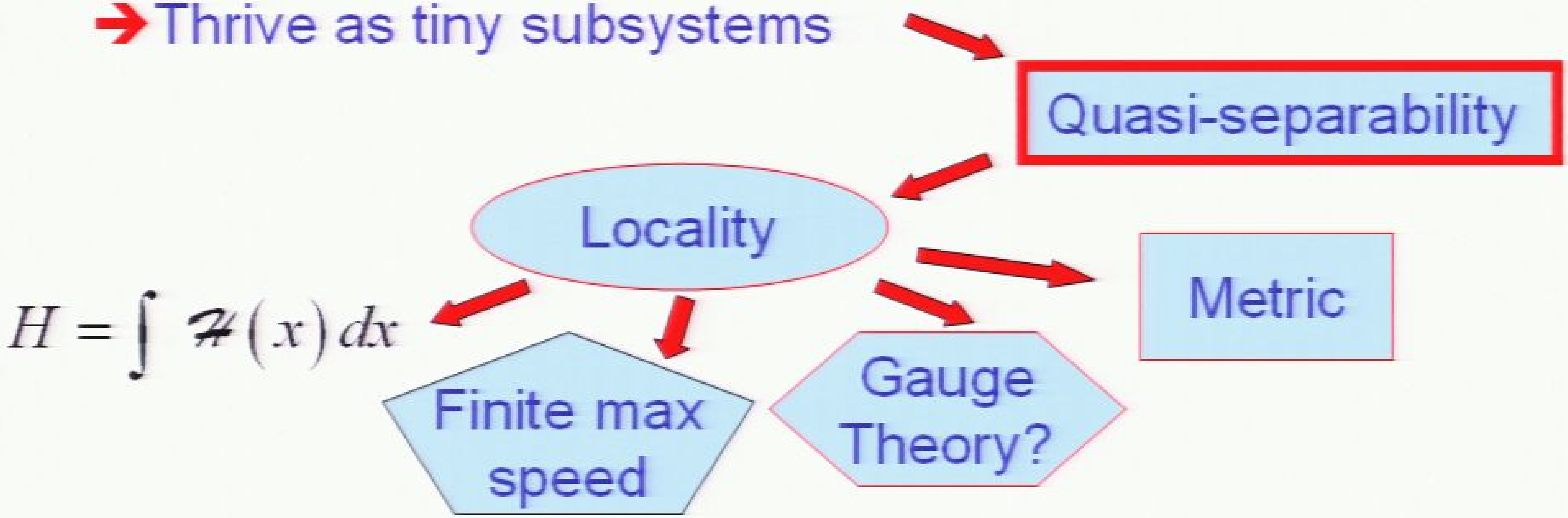

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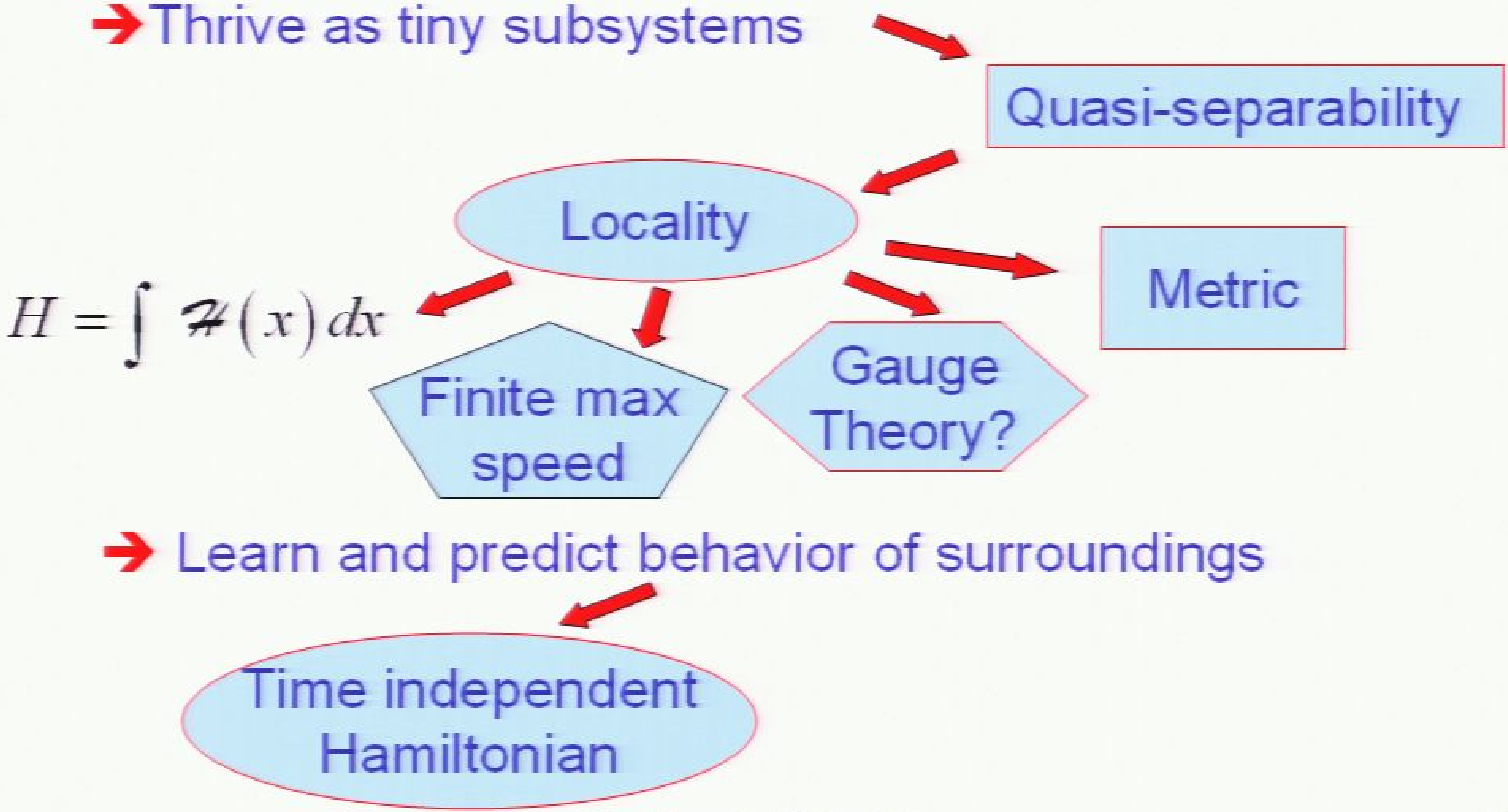

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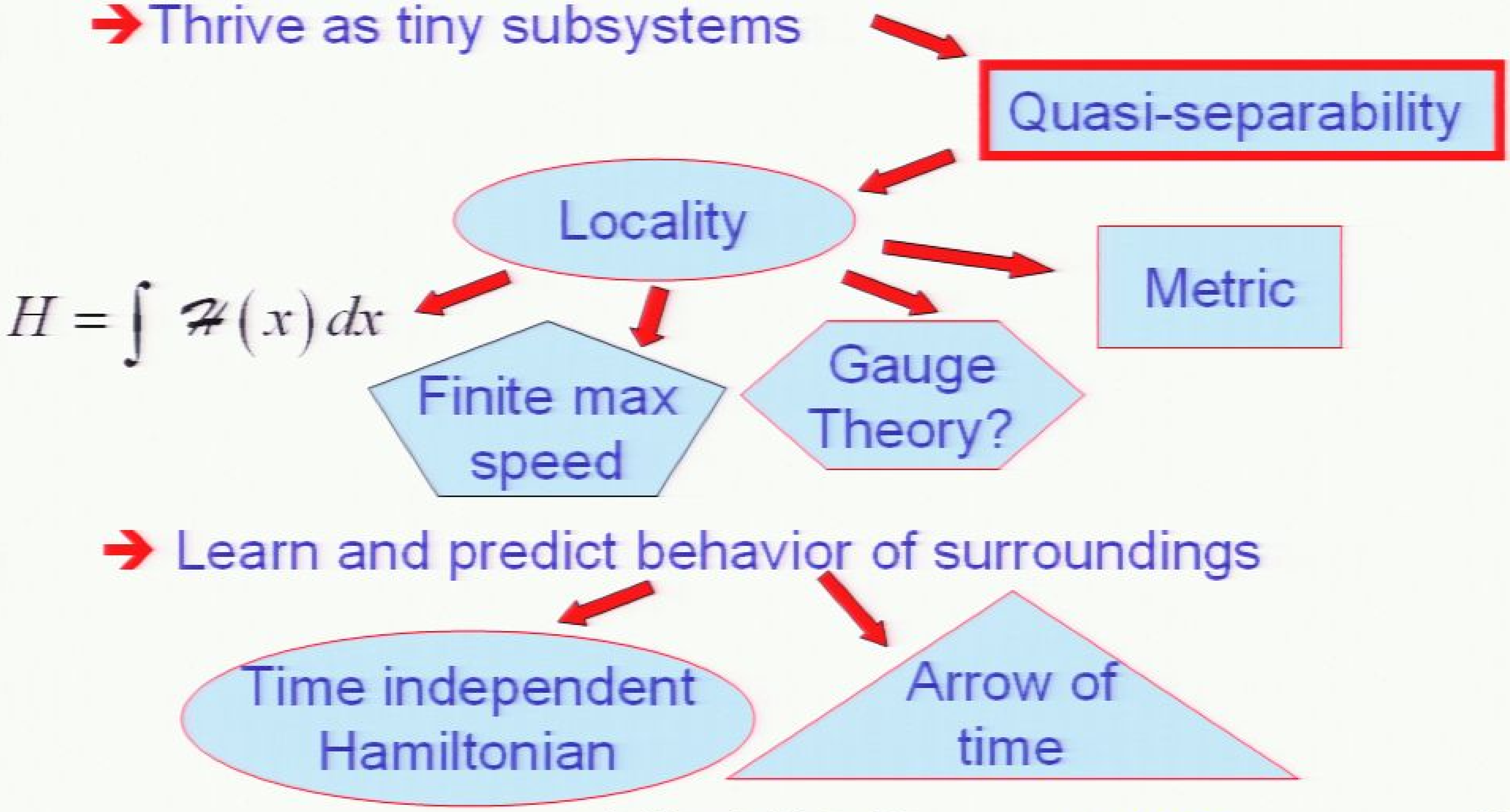

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Arrow of time

Outline

1) The clock ambiguity

2) **How one might do physics despite the clock ambiguity**

3) Case study: Field Theory “from” random matrices

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1) The clock ambiguity
2) How one might do physics despite the clock ambiguity
3) **Case study: Field Theory "from" random matrices**

For part 3:

➔ Choosing a clock subsystem at random leads to a random state undergoing random time evolution.

➔ How well does the Hamiltonian of the observed physical world match a random Hamiltonian?

Key point:

➔The fundamental point of comparison is the eigenvalue spectrum.

➔ Once the eigenvalue spectrum of the Hamiltonian generated by a “random clock choice” matches that of known physics “we are done” since the additional steps of identifying field operators, observables etc in the corresponding Hilbert space is “straightforward”.

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E-spectrum matching is a test these ideas must pass

3i) Wigner theory of random Hamiltonians

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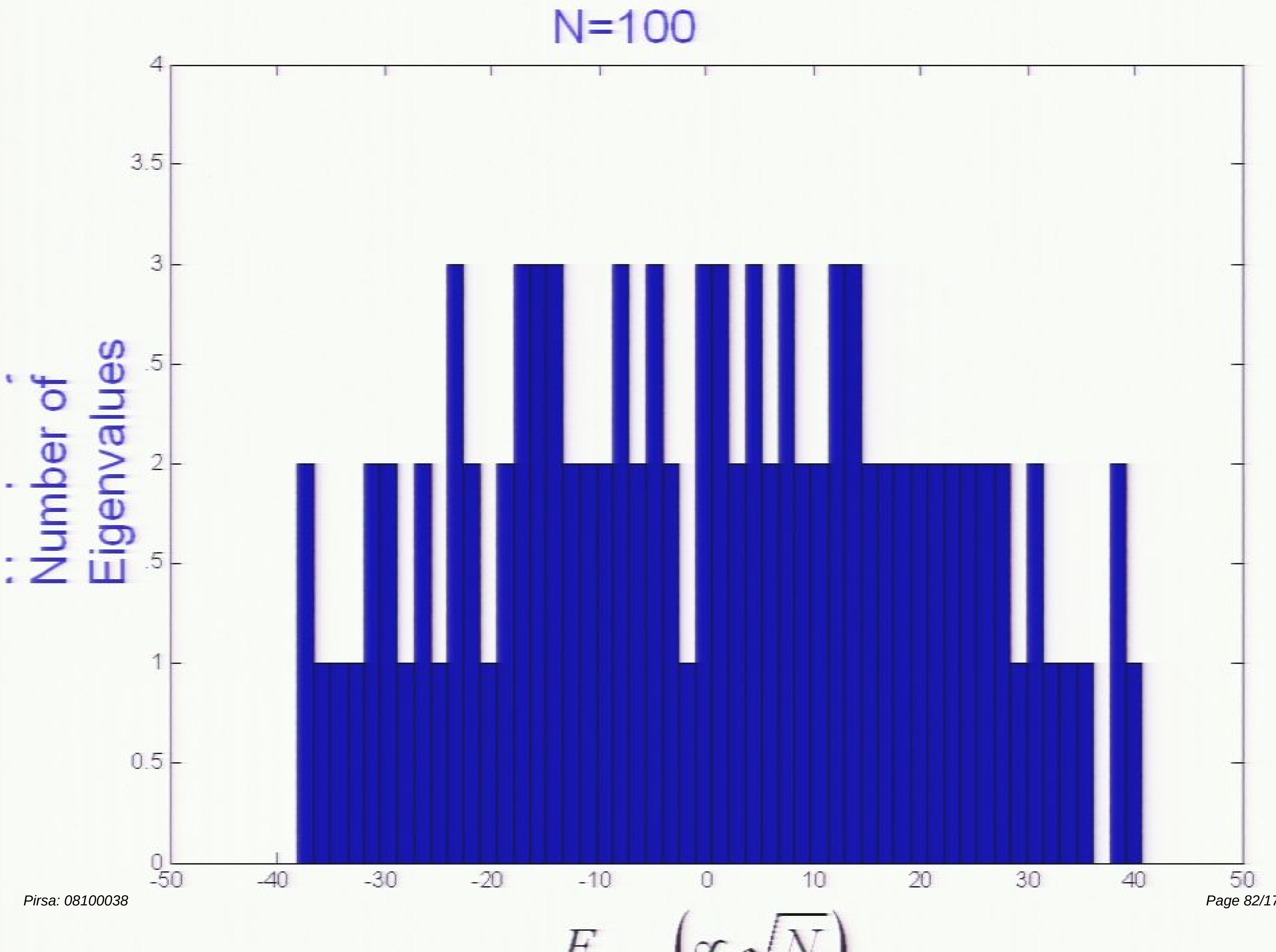
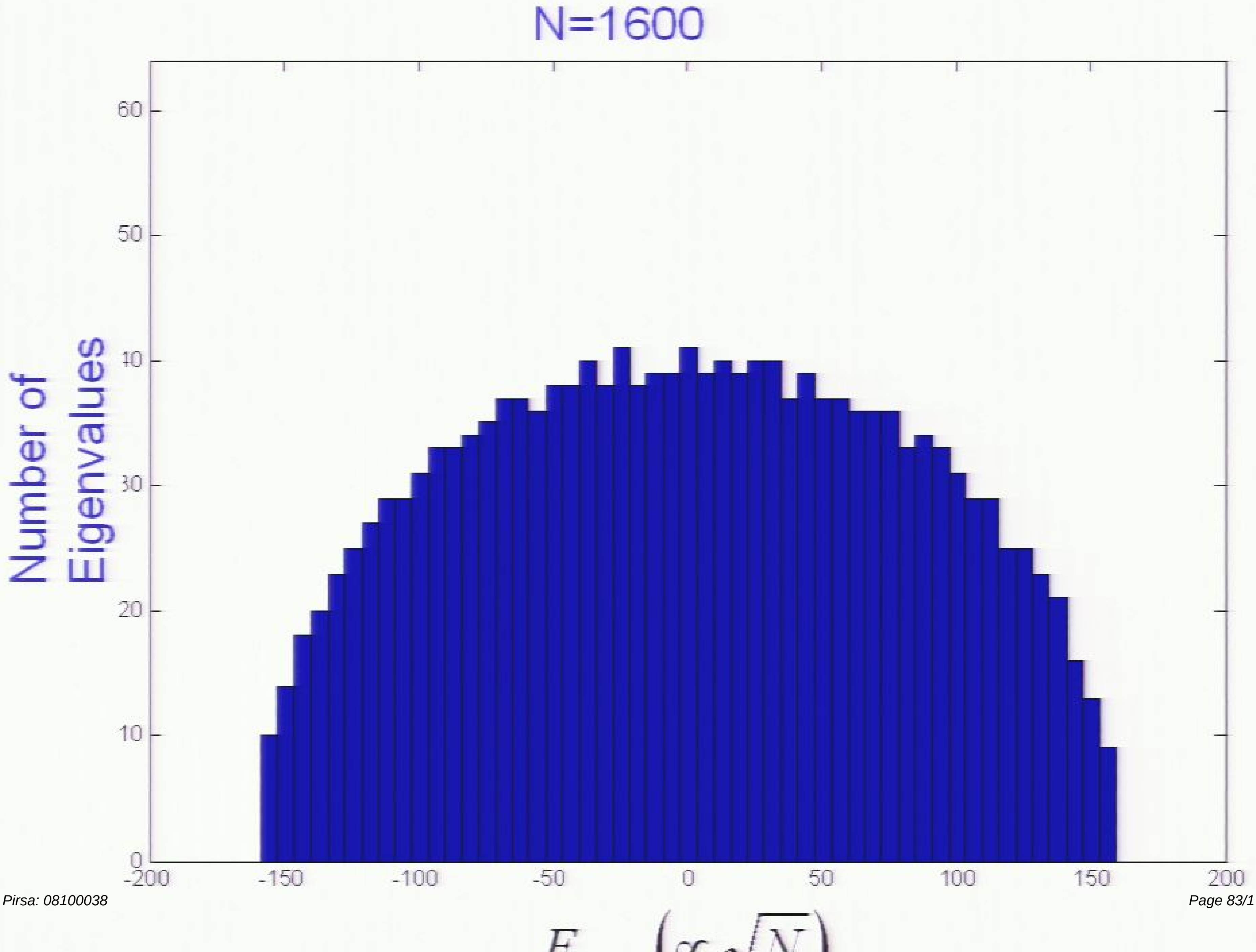
→ Generate a random Hamiltonian by selecting each matrix element from a normal distribution with width σ_E

→ Plot a histogram of the eigenvalues of the resulting Hamiltonian


N=100
Number of
Eigenvalues
4
3.5
3
.5
2
.5
1
0.5
0
-50
-40
-30
-20
-10
0
10
20
30
40
50
E (∝ √N)


N=1600
Number of Eigenvalues
0
10
20
30
40
50
60
-200
-150
-100
-50
0
50
100
150
200
E $(\propto \sqrt{N})$

Wigner semicircle rule

$$\frac{dN}{dE} = a\frac{N_R}{E_m}\sqrt{1-\left(\frac{E}{E_m}\right)^2}$$

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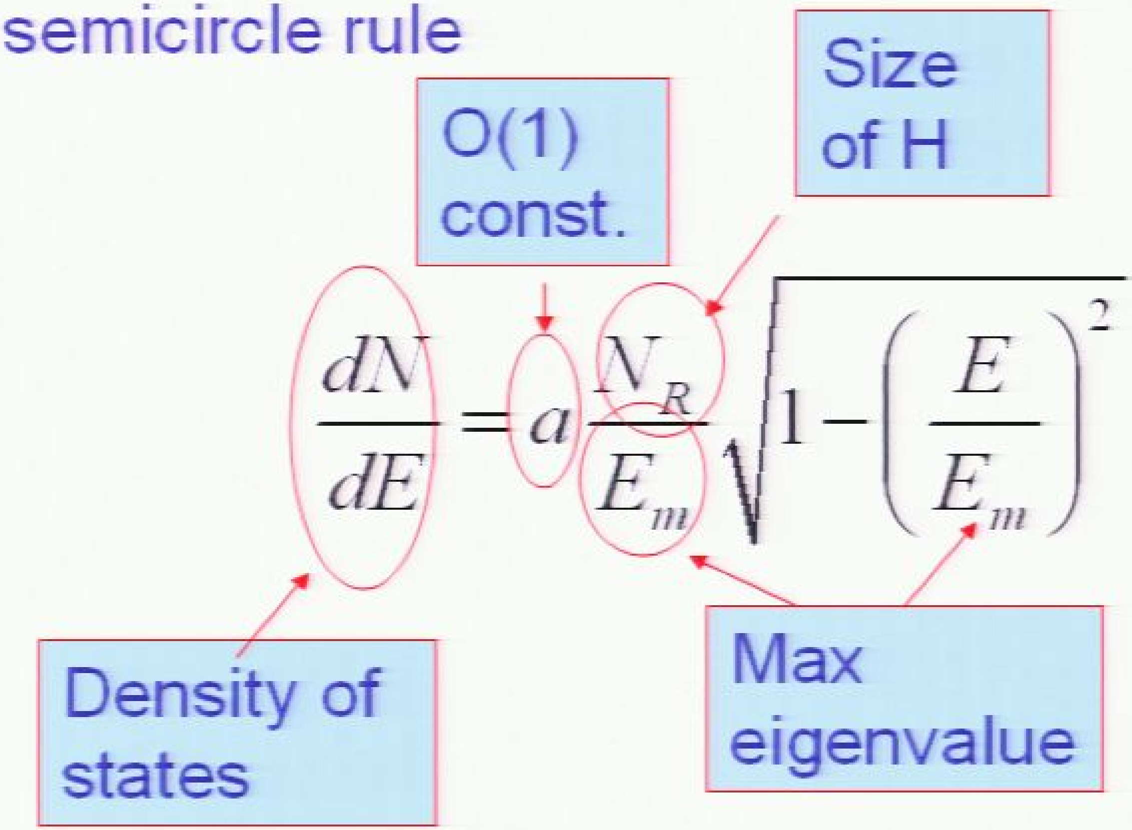
Density of states

Wigner semicircle rule

$$\underbrace{\frac{dN}{dE}}_{\text{Density of states}} = \overbrace{a}^{\text{O(1) const.}} \frac{\overbrace{N_R}^{\text{Size of H}}}{E_m} \sqrt{1 - \left(\frac{E}{E_m} \right)^2}$$

Wigner semicircle rule



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Density of states

Max eigenvalue

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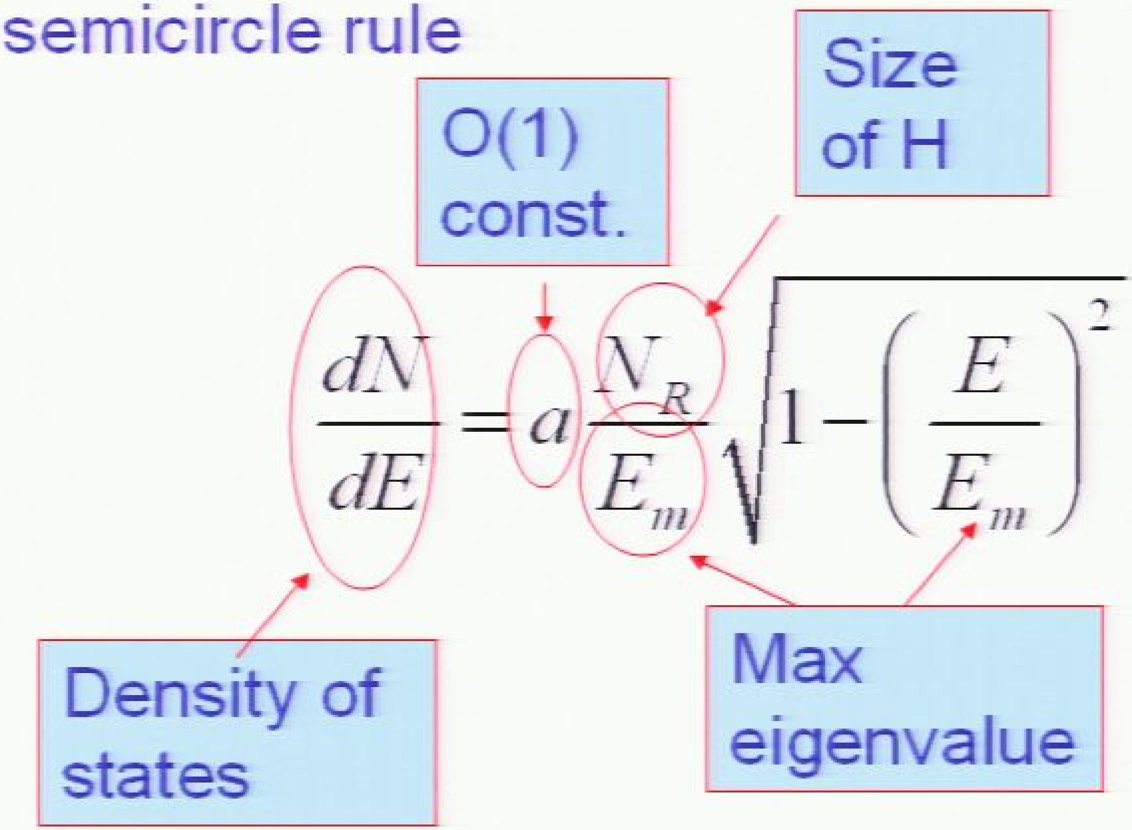

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N.B. $\sigma_E \propto \frac{E_M}{\sqrt{N_R}}$

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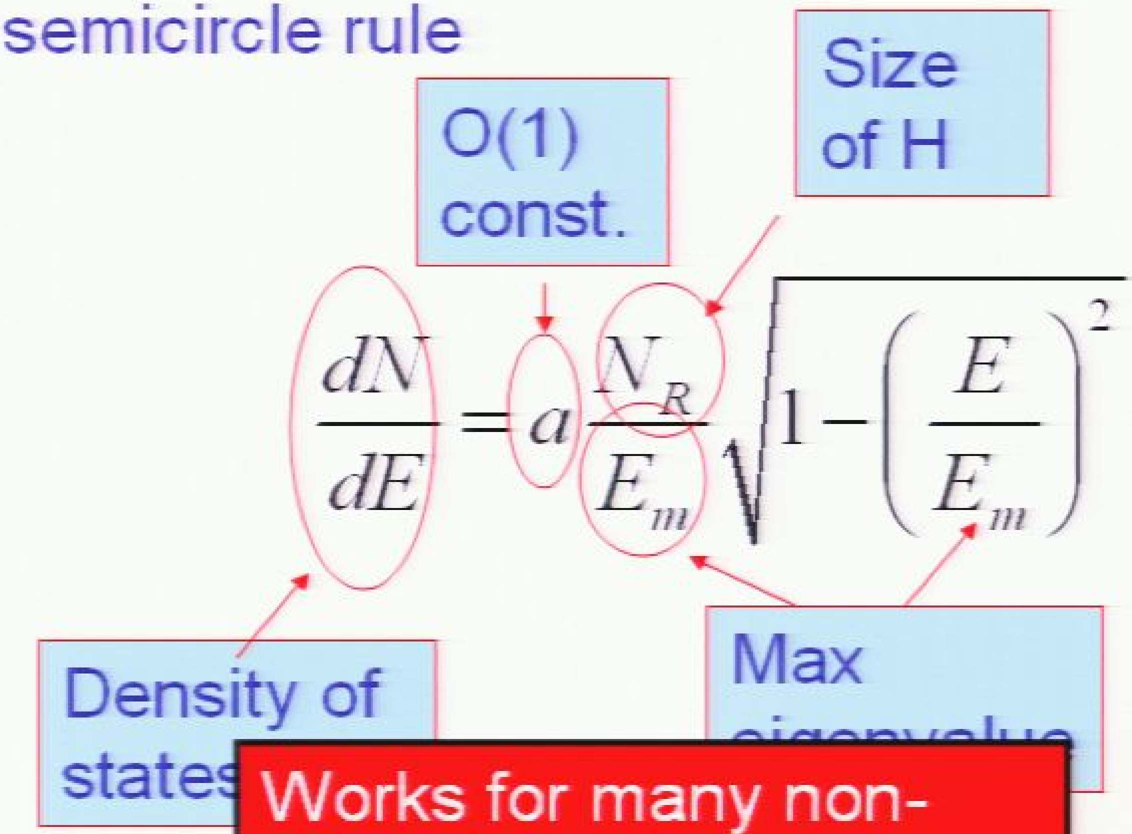

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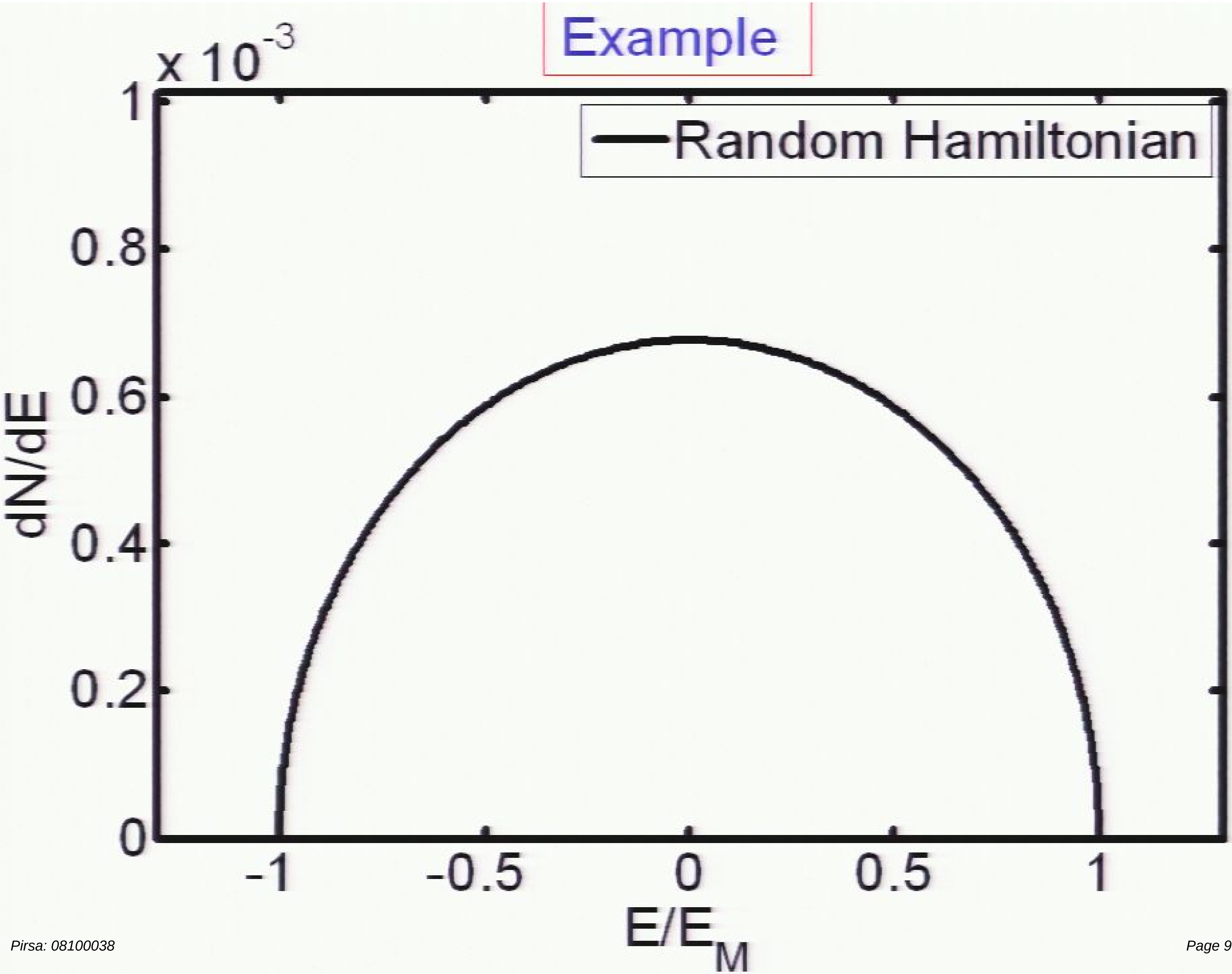
Density of states

Max eigenvalue

Works for many non-Gaussian distributions for the matrix elements

N.B. $\sigma_E \propto \frac{E_M}{\sqrt{N_R}}$

Example



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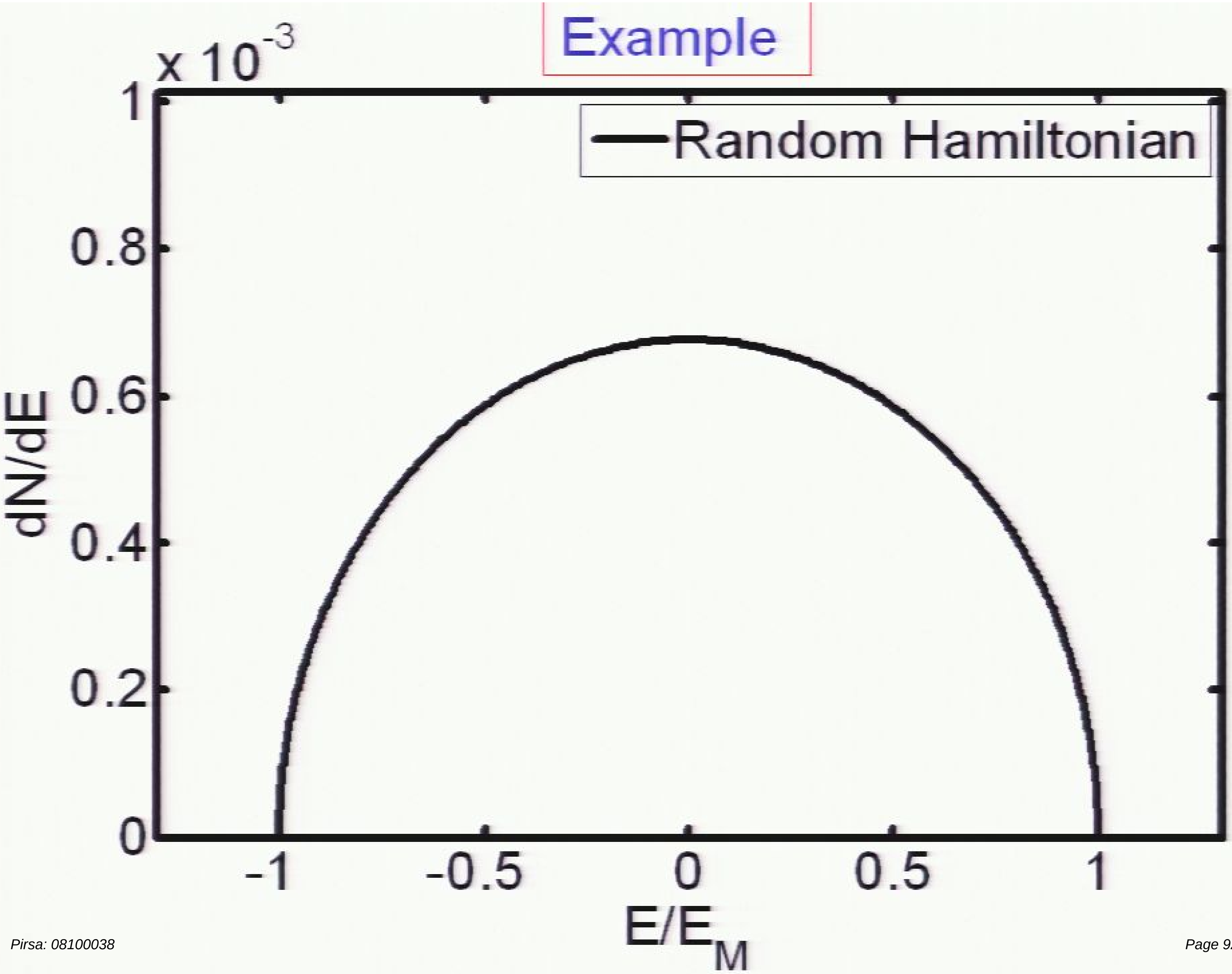

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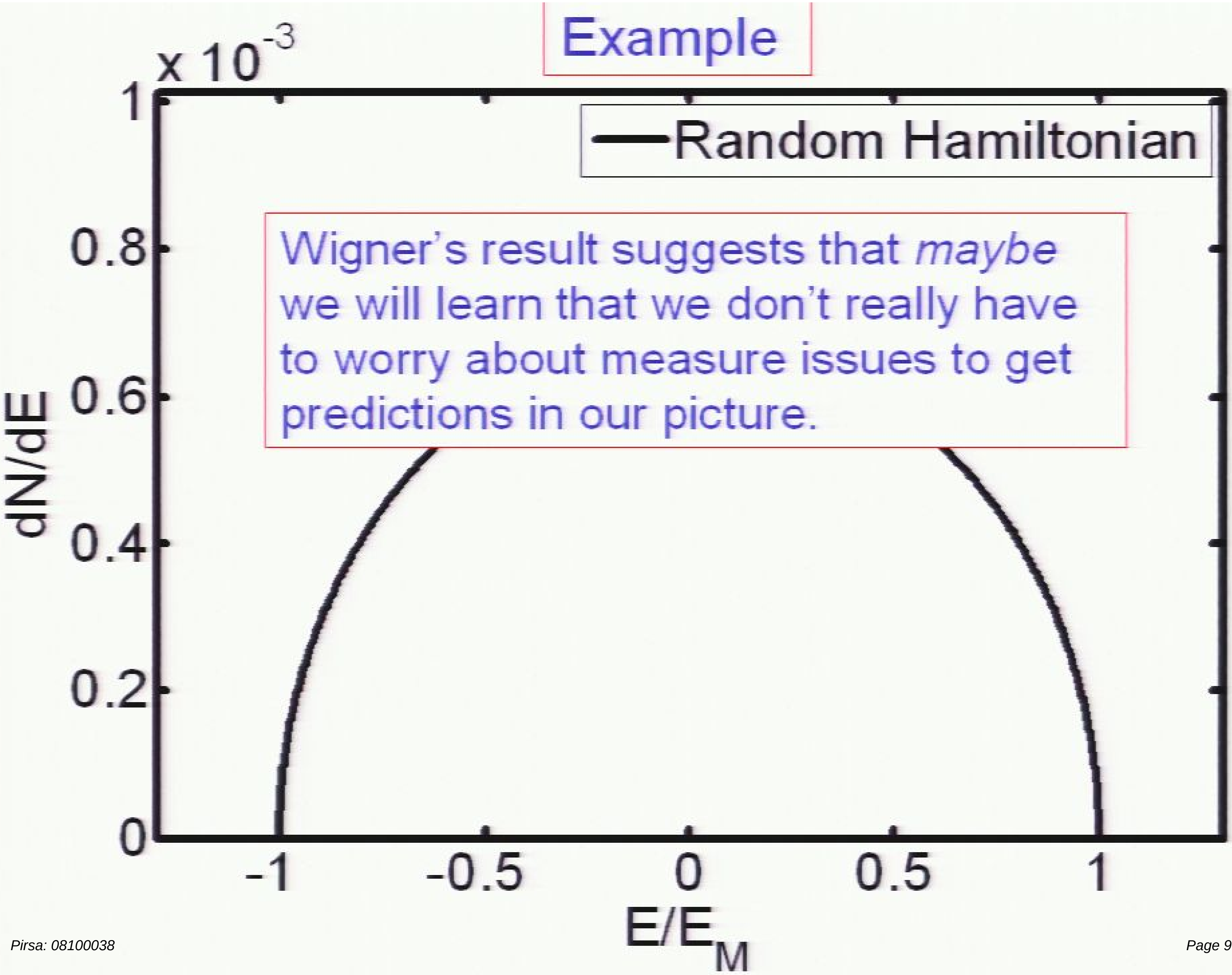

Wigner's result suggests that *maybe* we will learn that we don't really have to worry about measure issues to get predictions in our picture.

3ii) What is the eigenvalue spectrum of the standard model of particle physics (or whatever)?

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Consts.

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$$\left.\frac{dN}{dE}\right|_{FT} = \frac{B}{E}\exp\left\{b\left(\frac{E}{\Delta k}\right)^{1/2}\right\}$$

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k-space lattice
gap (2π/box size)

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(similar expression for 1+1 free Fermions)

well known CFT result

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(dimensions appear in *b*)

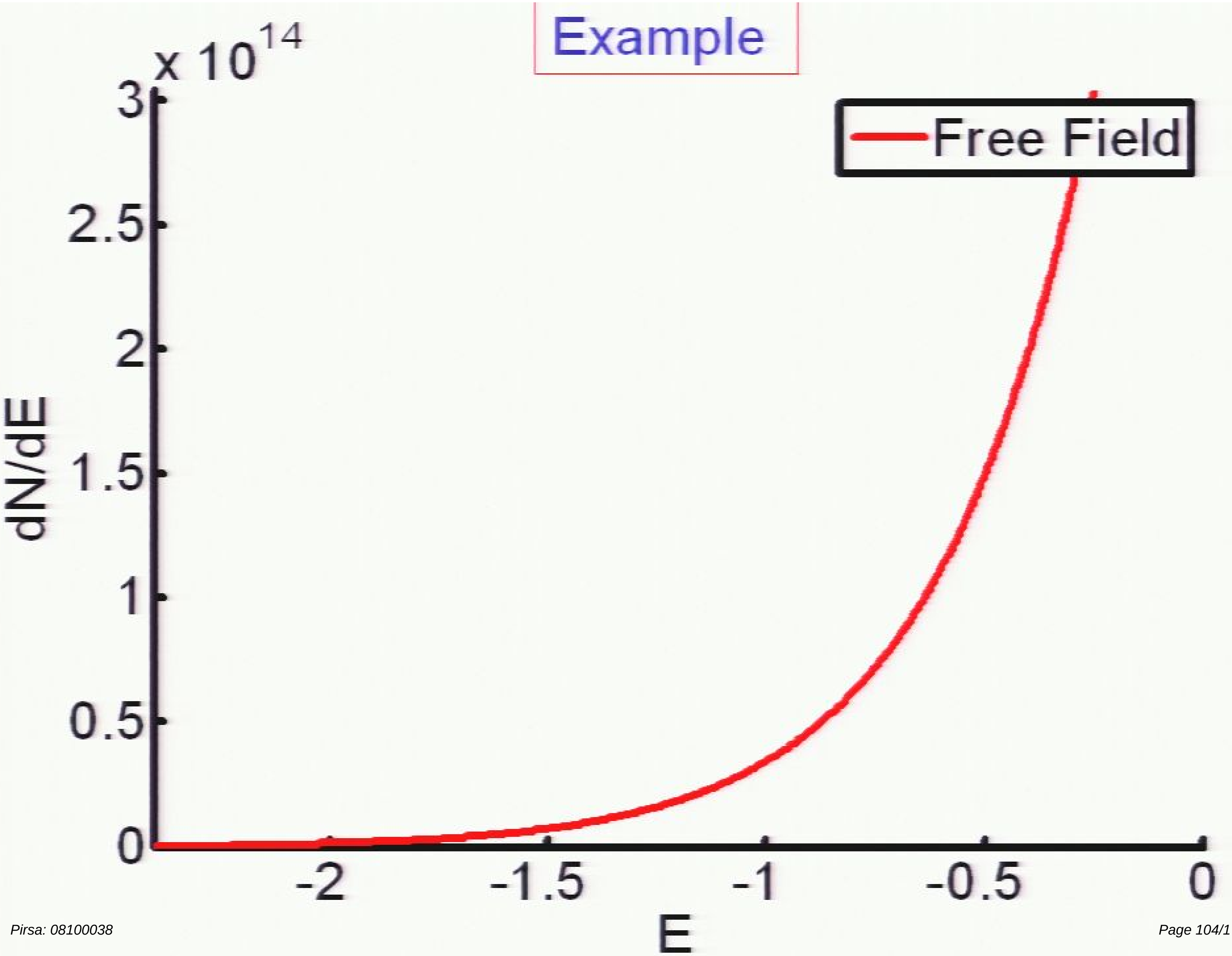
We consider generalized form

$$\boxed{\left.\frac{dN}{dE}\right|_{FT} = \frac{B}{E}\exp\left\{ b\left(\frac{E}{\Delta k}\right)^{\alpha} \right\}}$$

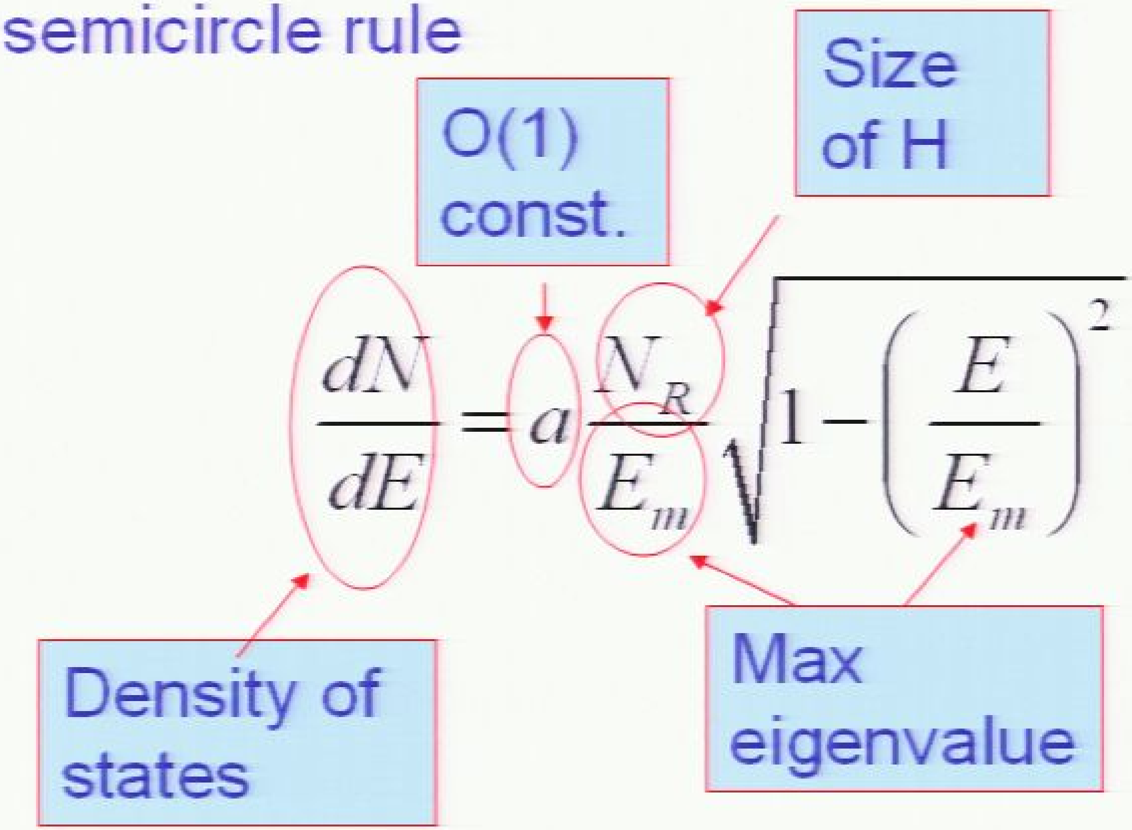
➔ A comment about gravity:

- Gravity critical part of known laws
- S_{BH} (or perhaps) S_Λ dominates S_{Univ}
- BUT: Not sure we need all those BH states to describe what we really know. Full GR & BH entropy may be a gross extrapolation.
- Stick to FT for now (which includes graviton)

Example



Wigner semicircle rule



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Max eigenvalue

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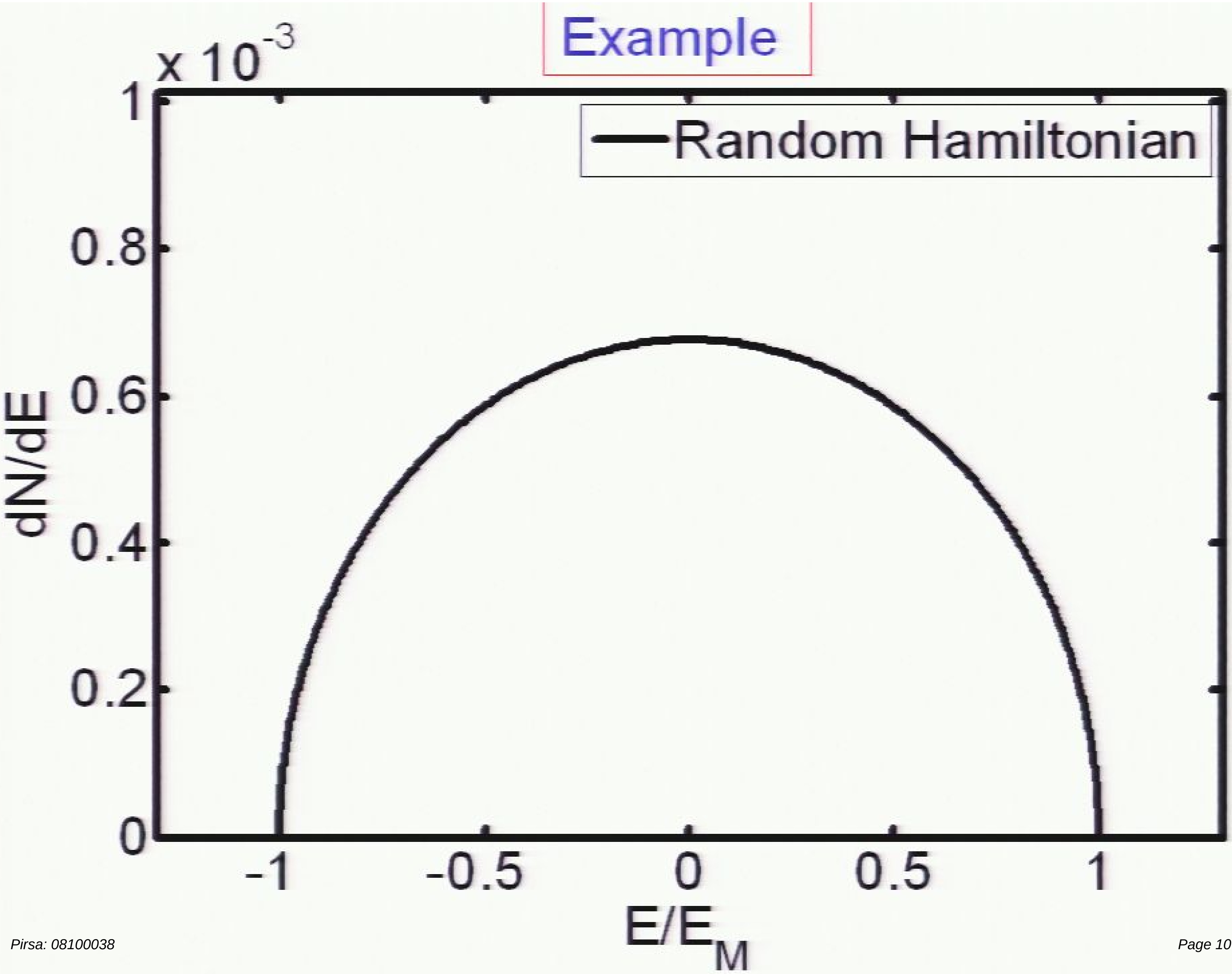

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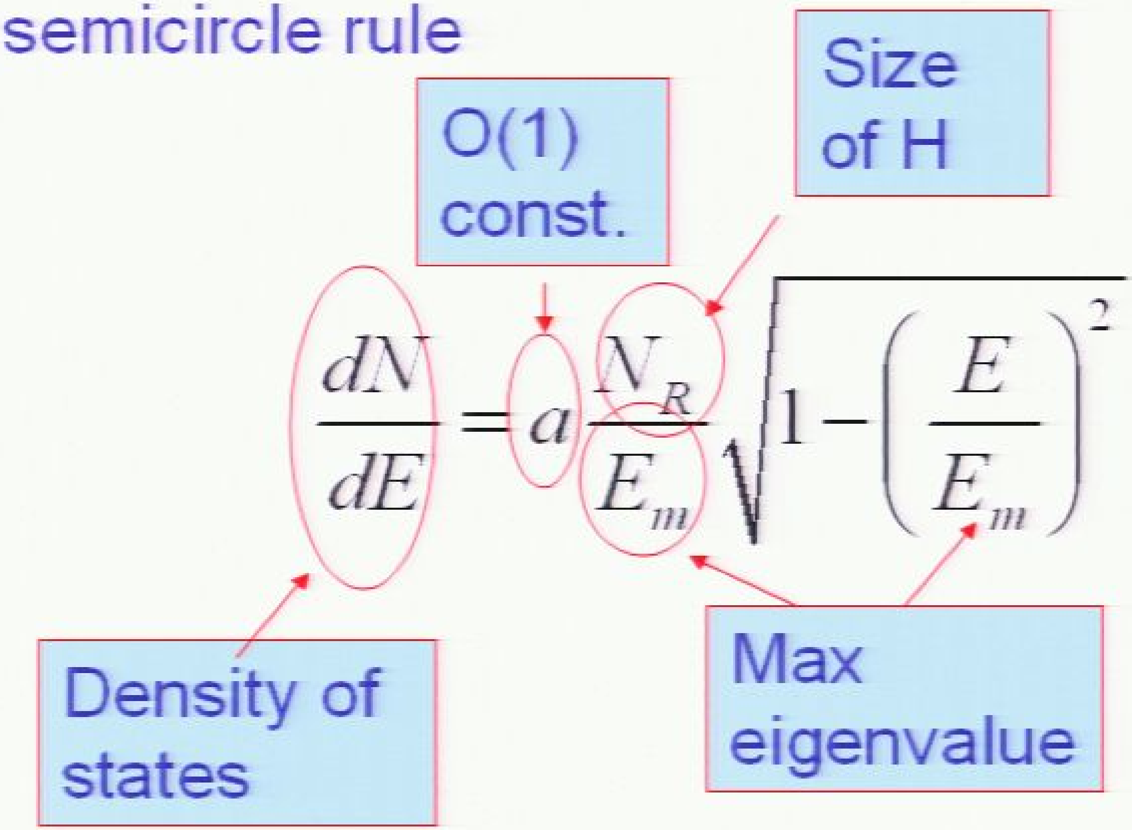

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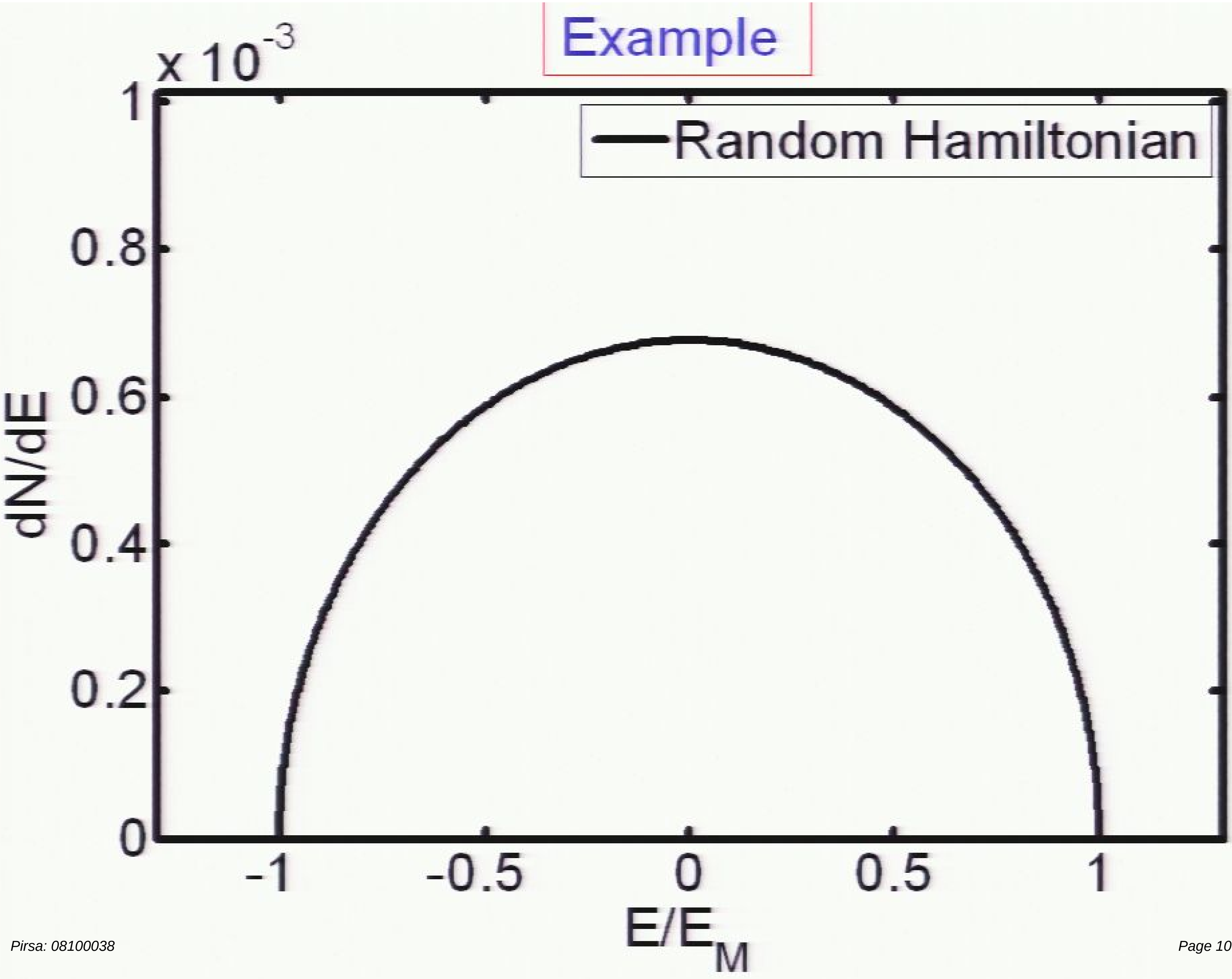

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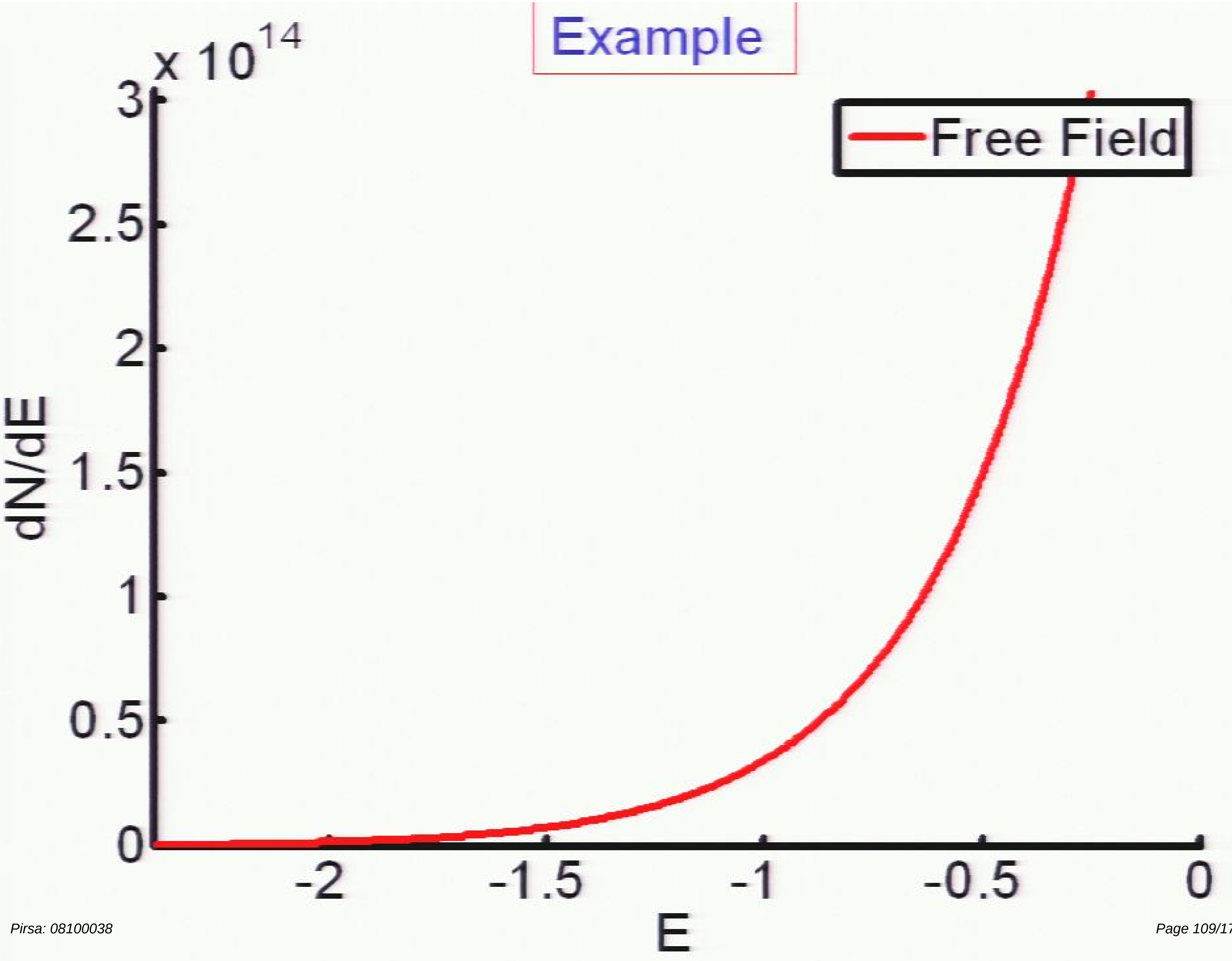

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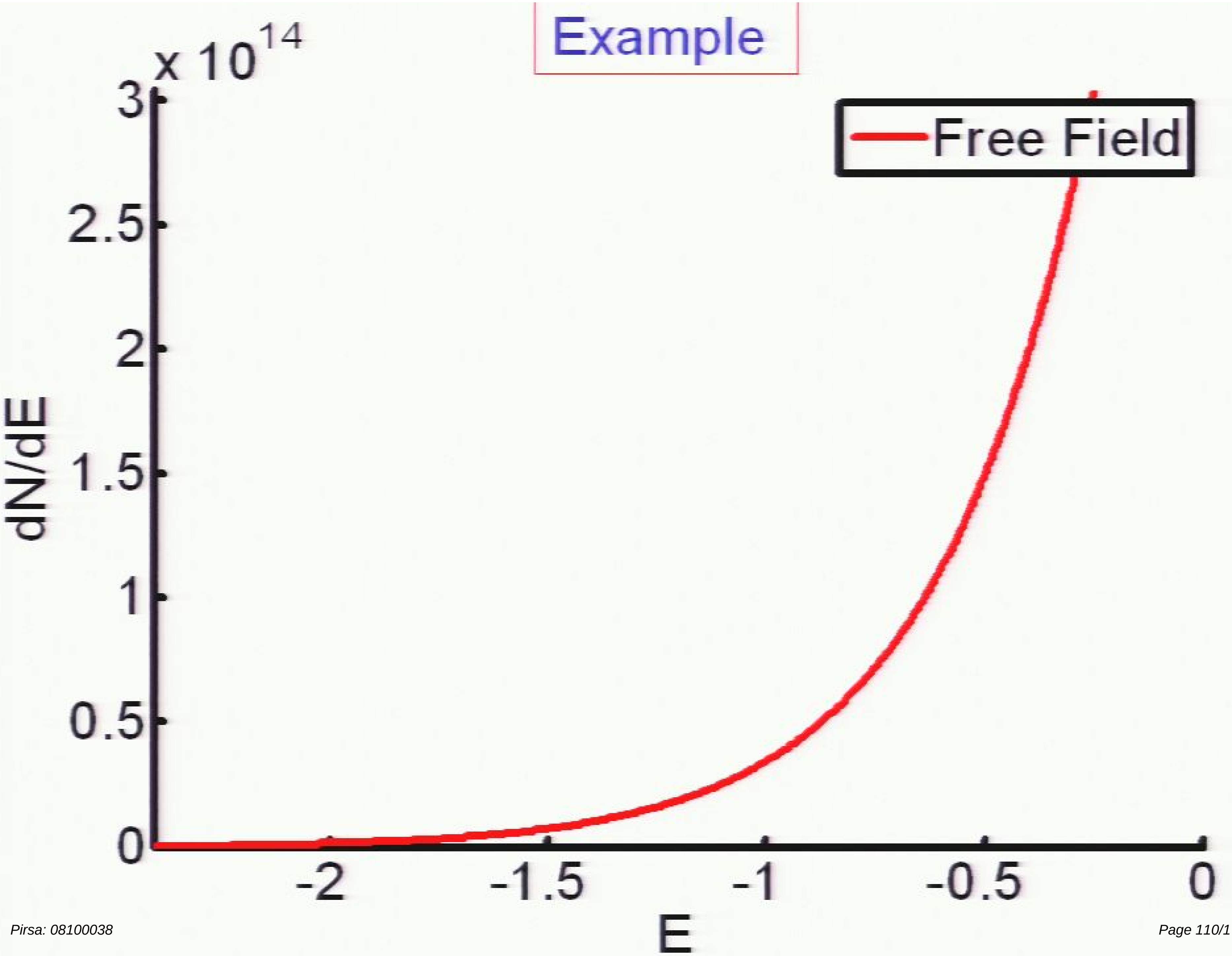

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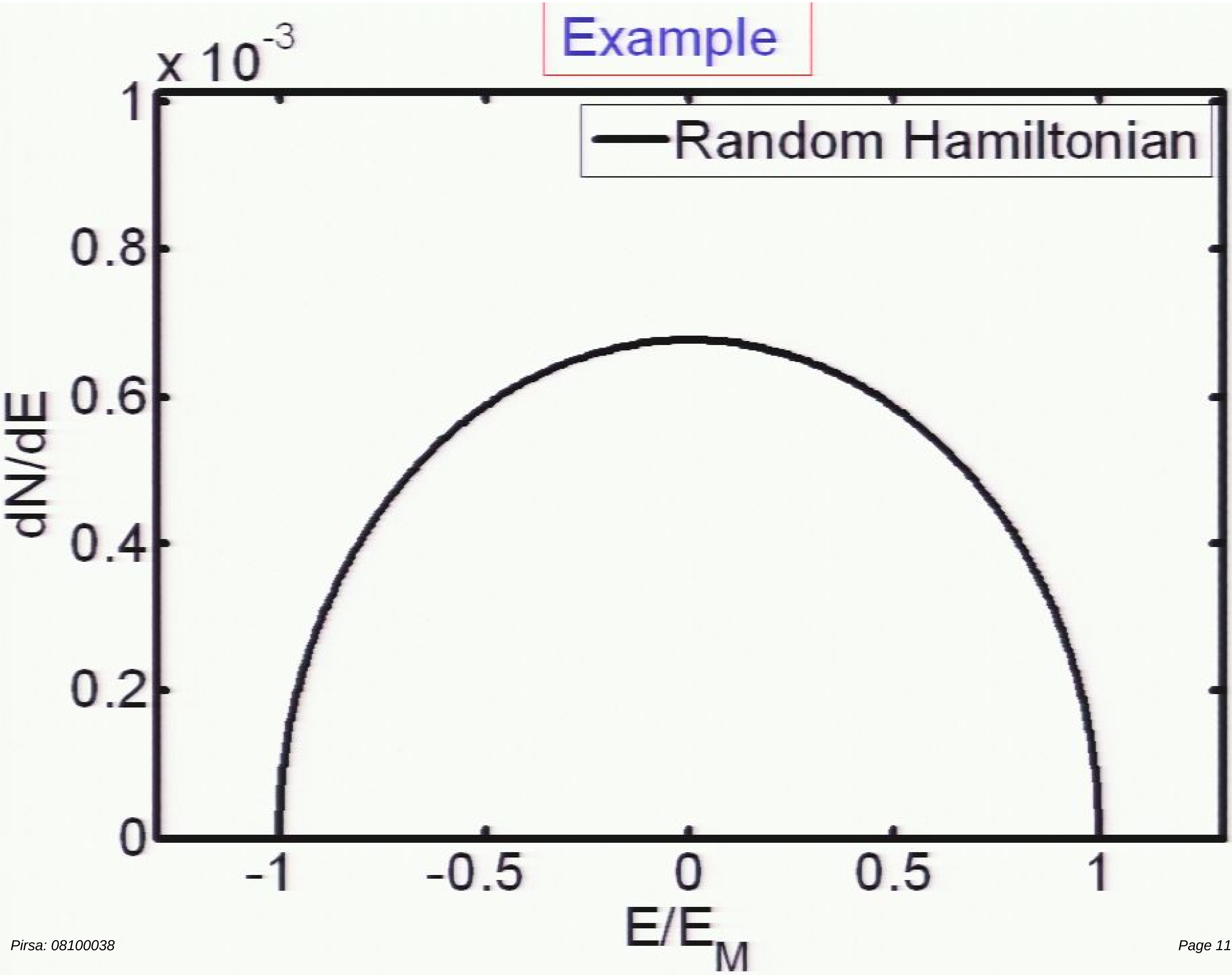

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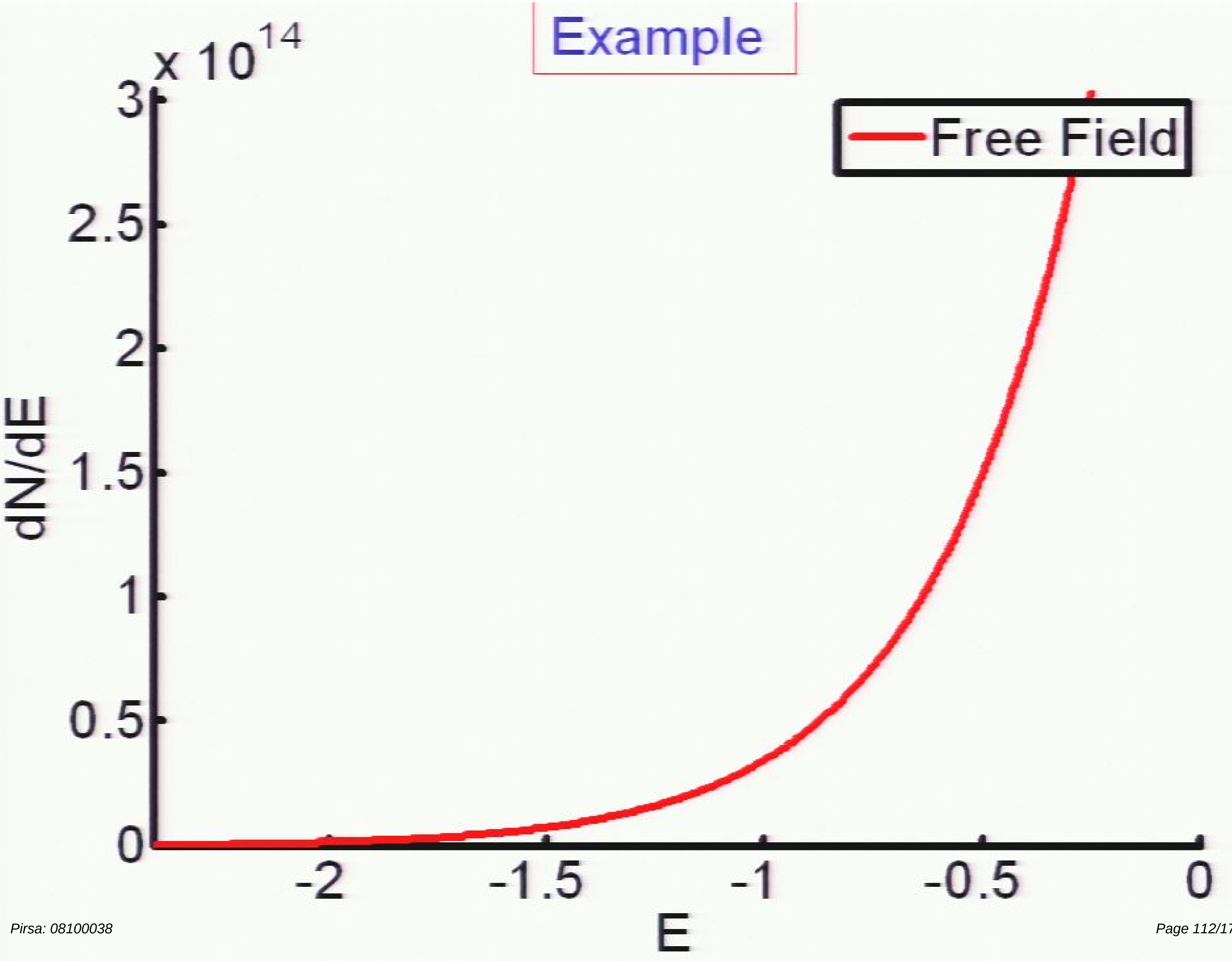

3iii) Compare "locally" using a Taylor series

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- ➔ Allow energy offset between two formulas
- ➔ Generalize Wigner formula to

$$\left.\frac{dN}{dE}\right|_R = a\frac{N_R}{E_m}\left(1-\left(\frac{E-E_S}{E_m}\right)^{\beta}\right)^{\gamma}$$

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Just curious (how sensitive?)

Energy shift

Taylor expand around some energy E_0 and set 0th order terms equal. Solve for N_R to get

$$N_R = \left(\frac{B}{\frac{2}{\pi}\left[1-\left(\frac{E_0-E_S}{E_M}\right)^2\right]^{1/2}} \frac{E_M}{E_0} \right) \exp\left\{ b\left(c\,\frac{E_0}{\Delta k} \right)^a \right\}$$

$\left.\frac{dN}{dE}\right|_R = \left.\frac{dN}{dE}\right|_F$ at 0th order

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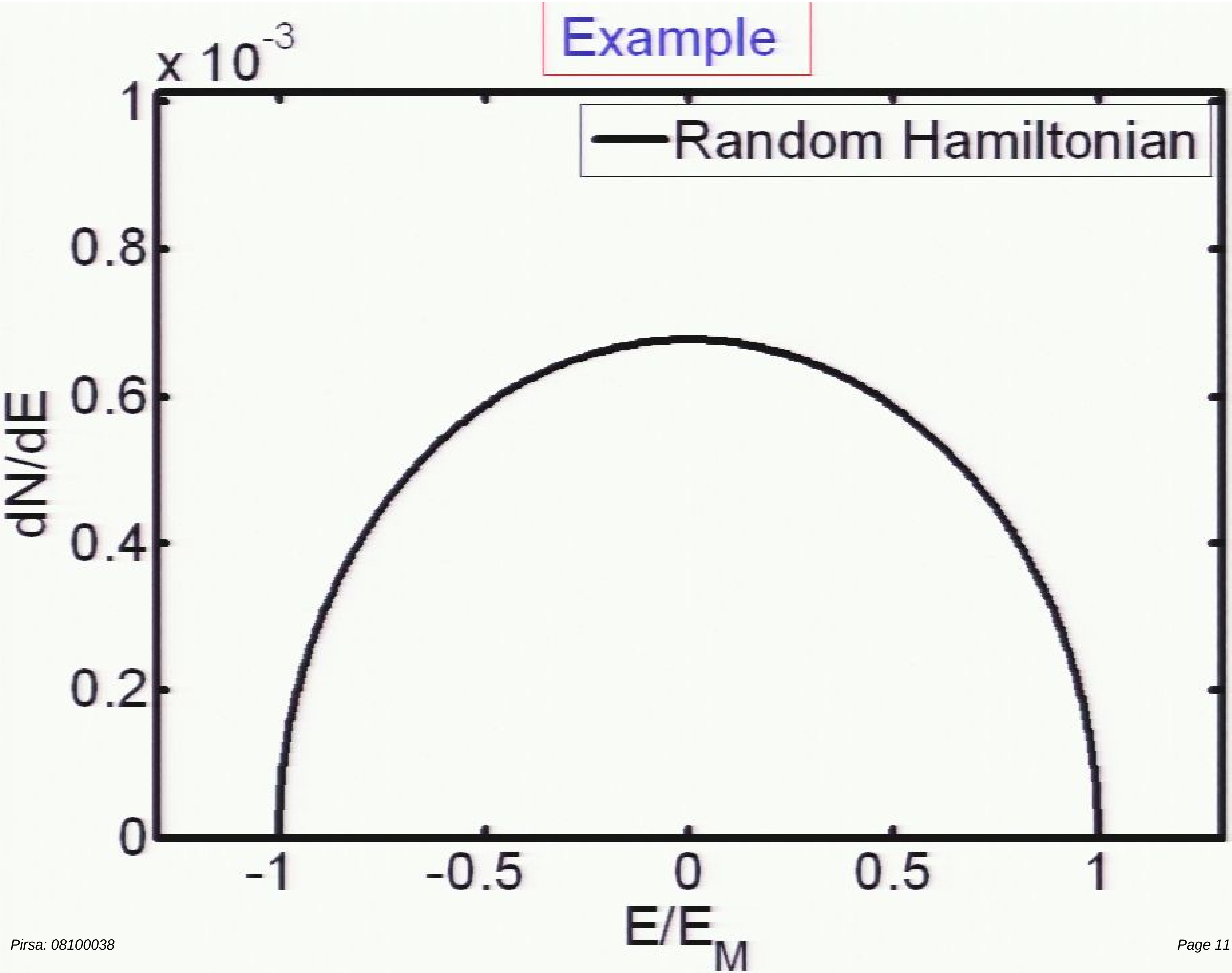

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“Energy of the universe”

$$N_R = \left(\qquad\qquad\qquad - \right) \exp\left\{ b \left(c \frac{E_0}{\Delta k} \right)^{\alpha} \right\}$$

k-space lattice gap (2π/box size)

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Dominant part of expression **(→ N_R exponentially large)**

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lattice

size)

“0th order equality ok”
(sets N_R)

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Dominant part of expression **(→** N_R **exponentially large)**

e lattice

size)

“0th order equality ok” (sets N)

Actually, sets a lower bound on N_R

$$\left.\frac{dN}{dE}\right|_R = \left.\frac{dN}{dE}\right|_F$$ at 0th order

- A comment on the time dependence of H

$$\left|\phi(t_i)\right\rangle_R \equiv \sum_j \alpha_{ij} \left|j\right\rangle_R$$

Q: Does randomizing these generally imply random time dependence for H?

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- A: α_{ij} and $\alpha_{(i+1)j}$ only give information about the time evolution of a *single state* at time t_i.
- The full H has info about the evolution of N states.
- Without loss of generality, assume a time independent H until one has taken N time steps.
- Any estimates of time steps/universe gives a number <<

$$N_R =\sim \exp\left\{ b\left(c\frac{E_0}{\Delta k} \right)^{\alpha} \right\}$$

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$$\boxed{\frac{m_P}{H_0} \approx 10^{60}} \qquad N_R = \sim \exp\left\{ b\left(c\frac{E_0}{\Delta k}\right)^{\alpha}\right\} \leftarrow \boxed{>10^{50}}$$

Taylor expand around some energy E_0 and set 0th and 1st order terms equal.

$$-\frac{E_0}{E_0-E_S}\frac{\left(\frac{E_0-E_S}{E_m}\right)^2}{\left(1-\left[\frac{E_0-E_S}{E_M}\right]^2\right)}=\alpha b\left(c\frac{E_0}{\Delta k}\right)^{\alpha}$$

$\left.\frac{dN}{dE}\right|_R=\left.\frac{dN}{dE}\right|_F$ at 1st order

Taylor expand around some energy E_0 and set 0th and 1st order terms equal.

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Huge number

k-space lattice gap (2π/box size)

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Huge number

Extremely close to unity

k-space lattice gap (2π/box size)

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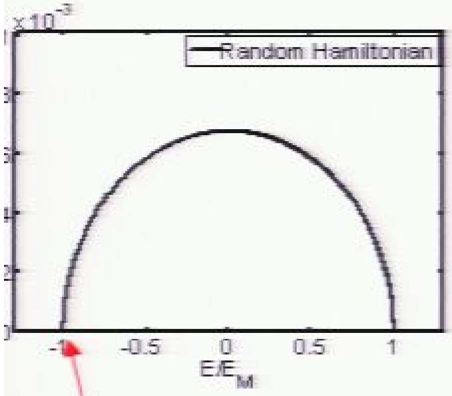
“Energy of the universe”



$$\frac{\left(\frac{E_0 - E_S}{E_m}\right)^2}{\left(1 - \left[\frac{E_0 - E_S}{E_M}\right]^2\right)} = \alpha b \left(c \frac{E_0}{\Delta k} \right)^{\alpha}$$

Huge number

Close to edge of semicircle

Extremely close to unity

k-space lattice gap (2π/box size)

$\left.\frac{dN}{dE}\right|_R = \left.\frac{dN}{dE}\right|_F$ at 1st order

Taylor expand around some energy E_0 and set 0th and 1st order terms equal. Solve for E_S

$$E_S = E_0 + E_M\left(1 - \varepsilon\right)$$

extremely small

$$\left.\frac{dN}{dE}\right|_R = \left.\frac{dN}{dE}\right|_F$$ at 1st order

A. Albrecht PI Oct 08

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"1st order equality ok" (sets E_S)

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A. Albrecht PI Oct 08

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Shift contribution from "energy of the universe". Any relation to cosmological constant?

"1st order equality ok" (sets E_S)

$$\left.\frac{dN}{dE}\right|_R = \left.\frac{dN}{dE}\right|_F$$ at 1st order

Taylor expand around some energy E_0

2nd order terms can not be set equal. One gets

$$\frac{\left(\left.\frac{dN}{dE}\right|_F - \left.\frac{dN}{dE}\right|_R \right)_2}{\left.\frac{dN}{dE}\right|_{E_0}} \approx \left(\left(\frac{E_0}{\Delta k} \right)^{\alpha} \frac{\Delta E}{E_0} \right)^2 \equiv \Delta_2$$

$\left.\frac{dN}{dE}\right|_R \neq \left.\frac{dN}{dE}\right|_F$ at 2nd order

Taylor expand around some energy E_0

2nd order terms can not be set equal. One gets

$$\frac{\left(\left.\frac{dN}{dE}\right|_F - \left.\frac{dN}{dE}\right|_R\right)_2}{\left.\frac{dN}{dE}\right|_{E_0}} \approx \left(\left(\frac{E_0}{\Delta k}\right)^{\alpha} \frac{\Delta E}{E_0}\right)^2 \equiv \Delta_2$$

k-space lattice gap (2π/box size)

"Energy of universe"

$\left.\frac{dN}{dE}\right|_R \neq \left.\frac{dN}{dE}\right|_F$ at 2nd order

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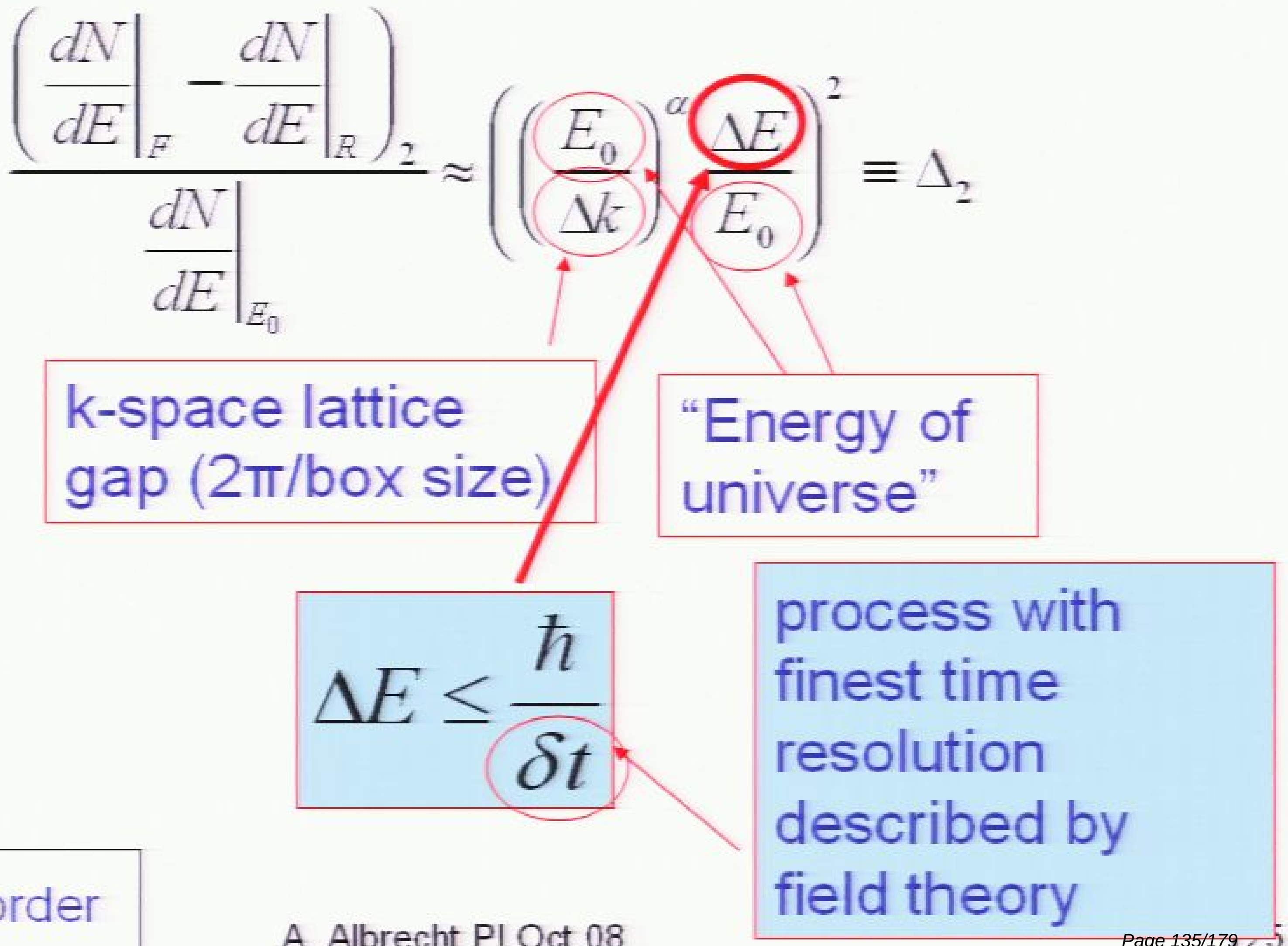

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k-space lattice gap (2π/box size)

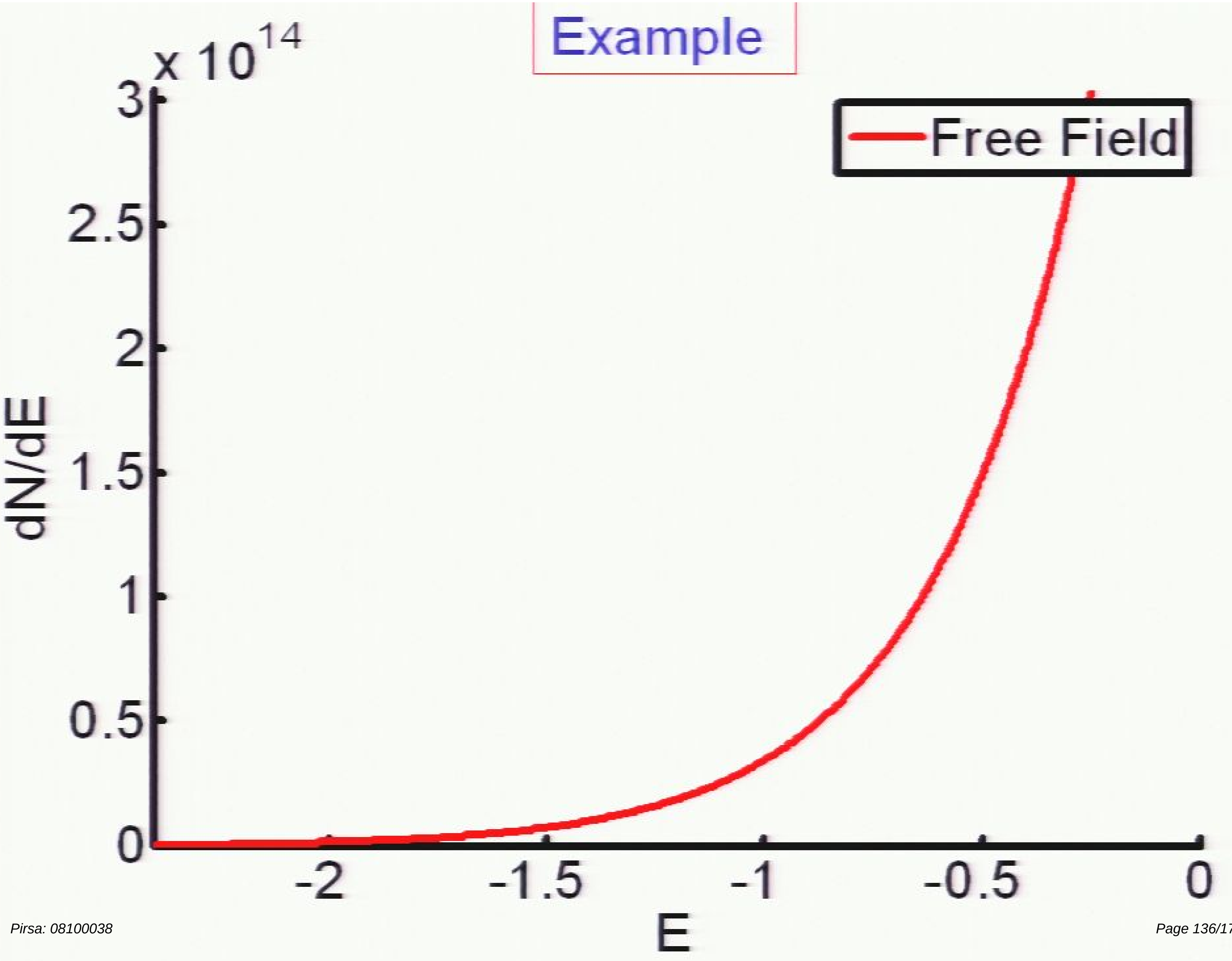
"Energy of universe"

$$\Delta E \leq \frac{\hbar}{\delta t}$$

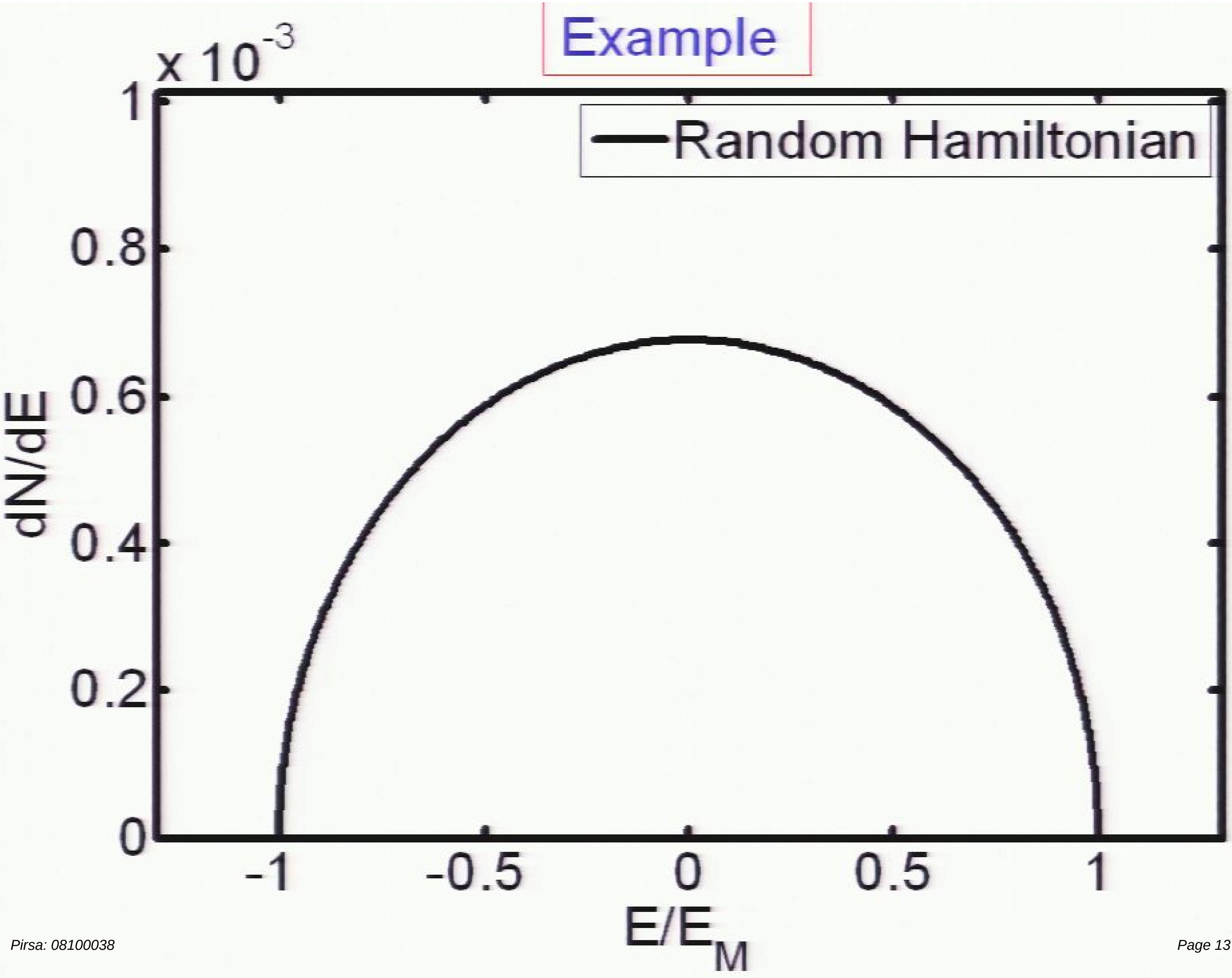
process with finest time resolution described by field theory

$\left.\frac{dN}{dE}\right|_R \neq \left.\frac{dN}{dE}\right|_F$ at 2nd order

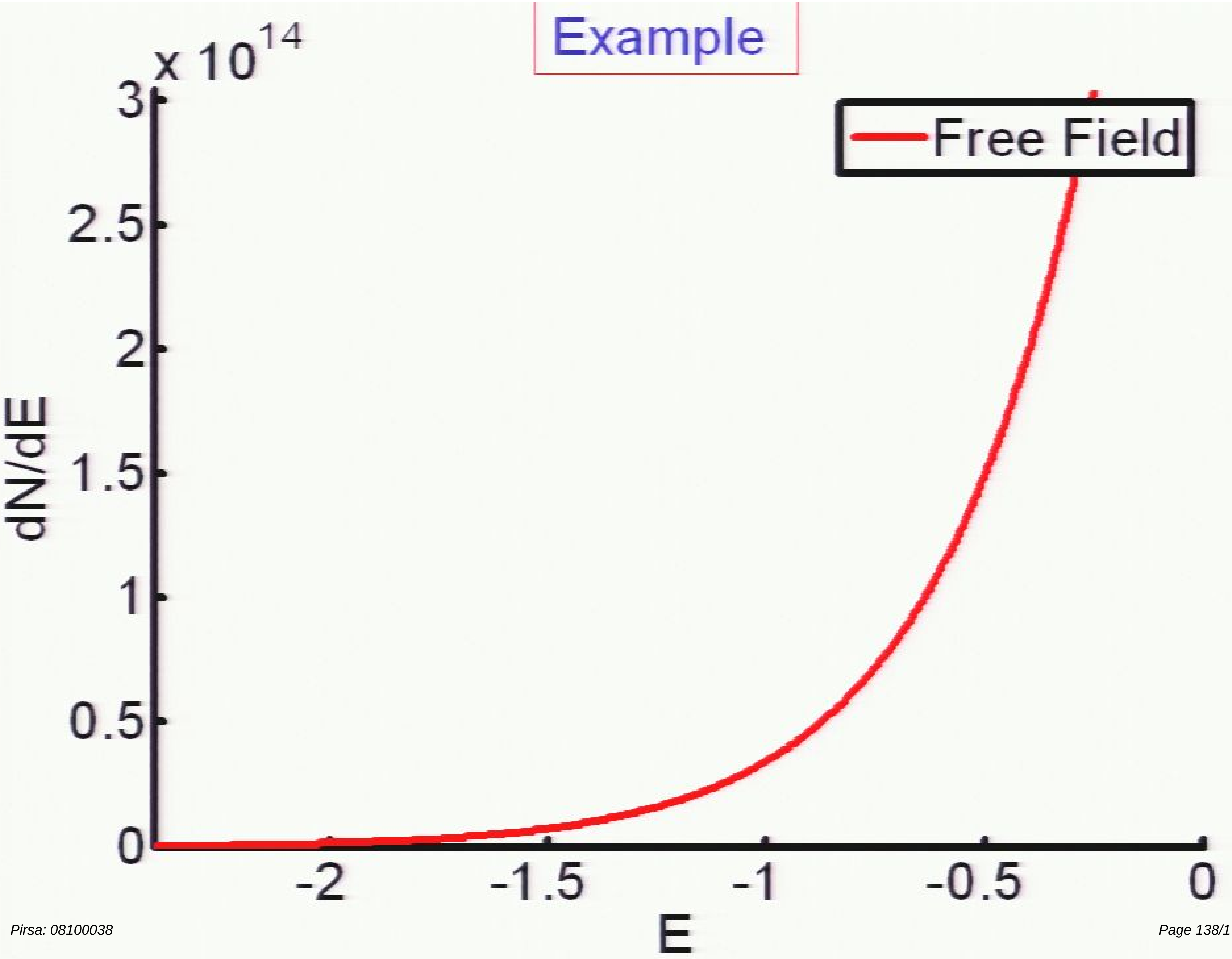
Example



Example



Example



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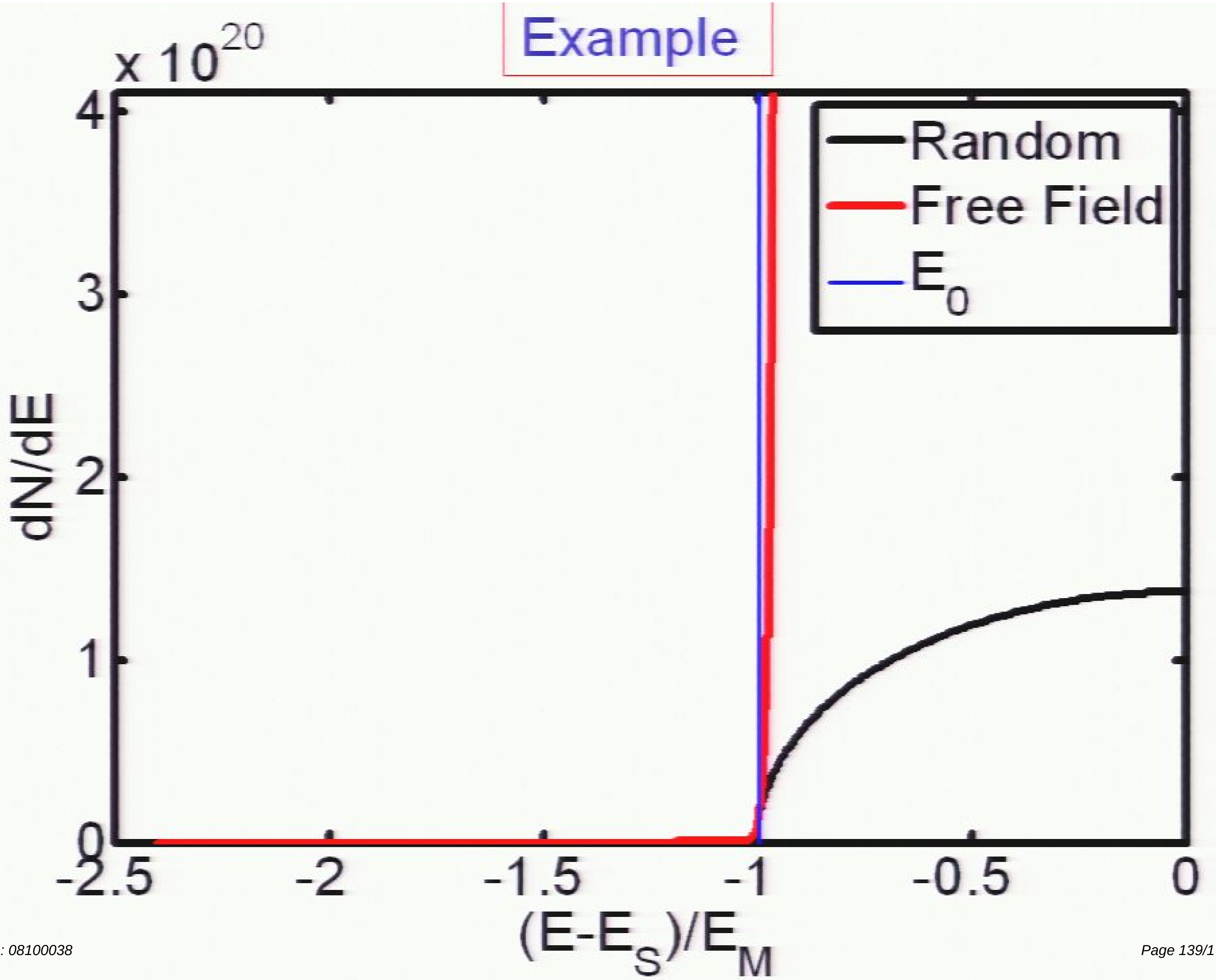
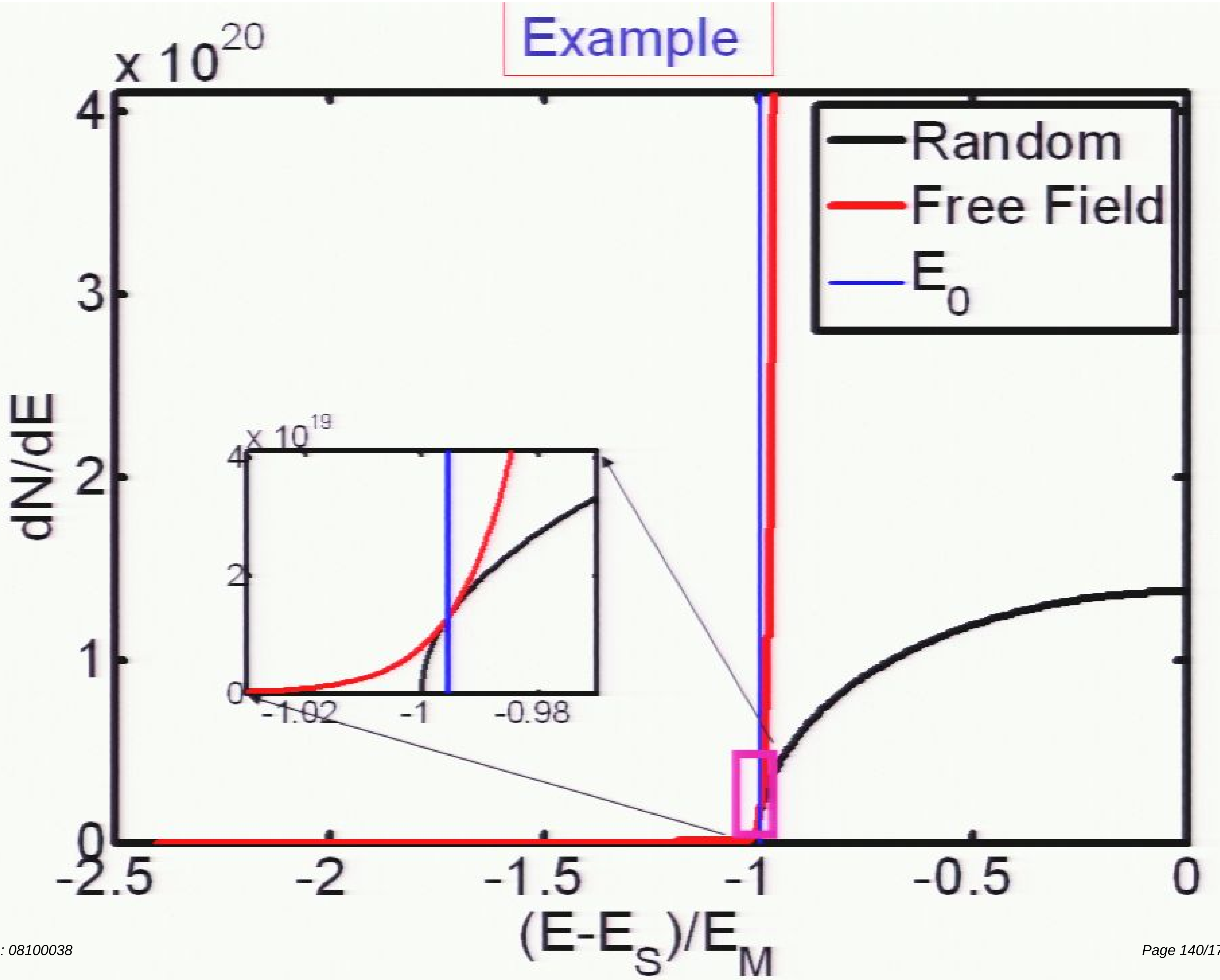
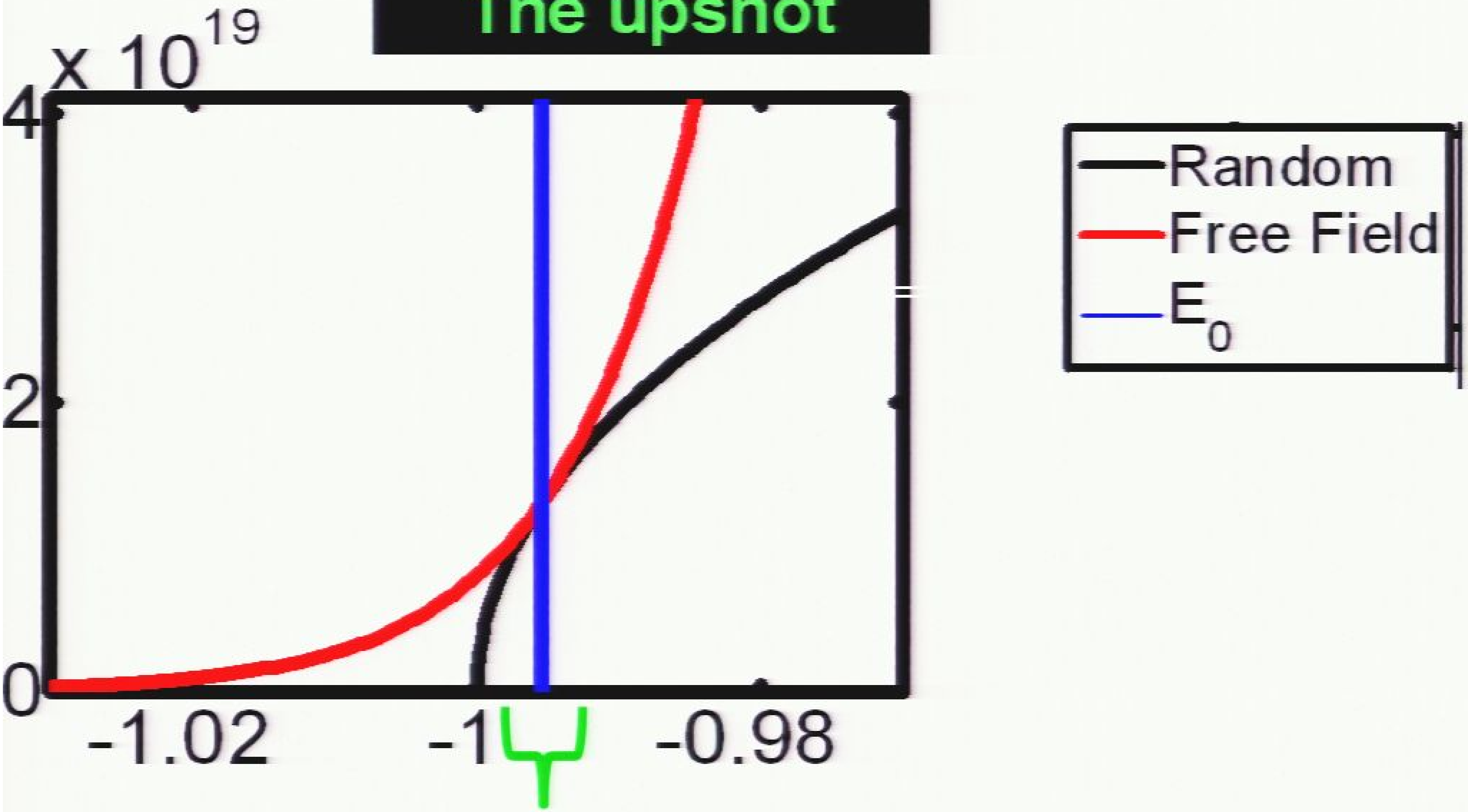


Example

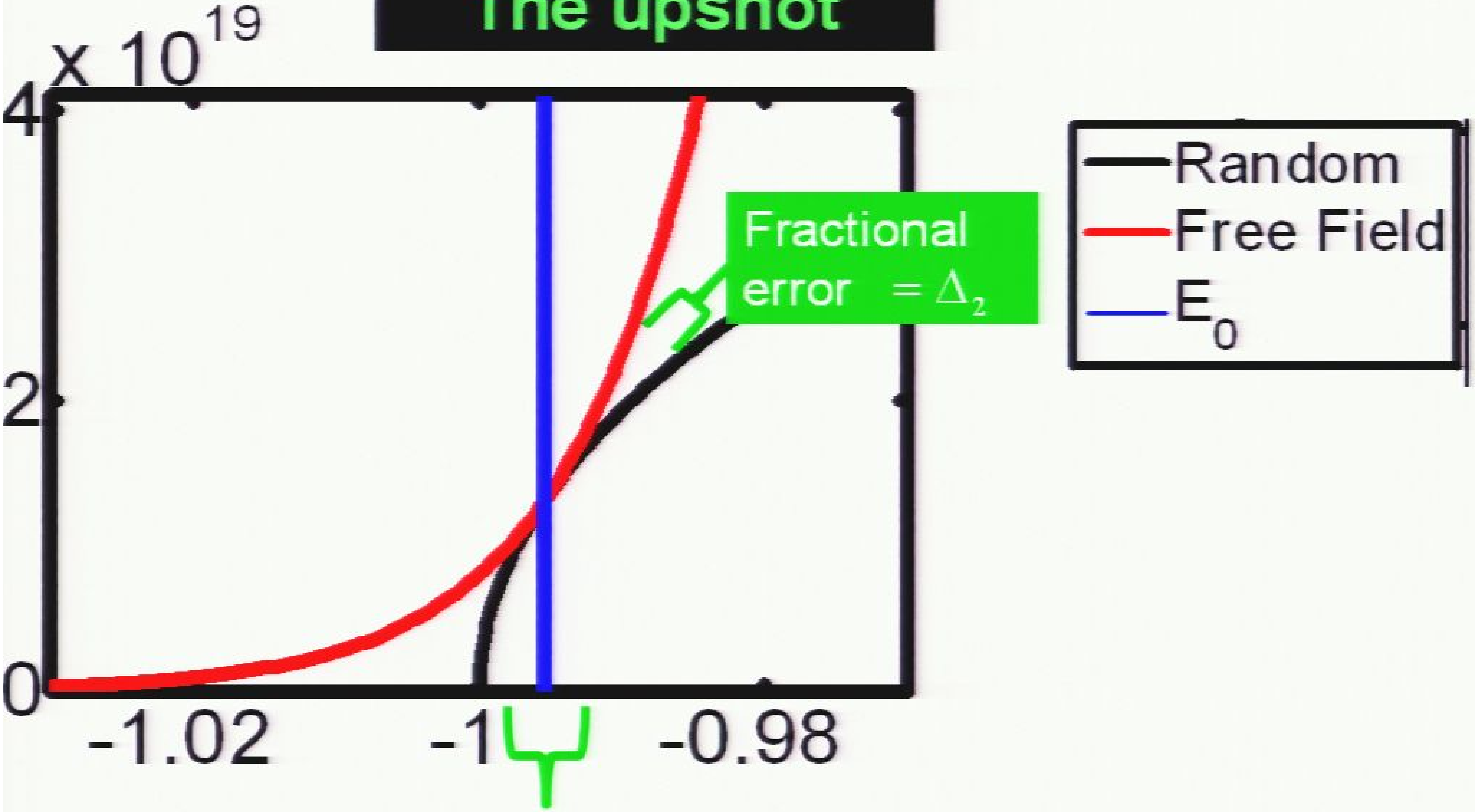

x 10^20
4
3
2
1
0
-2.5
-2
-1.5
-1
-0.5
0
dN/dE
(E-E_S)/E_M
Random
Free Field
E_0
x 10^19
4
2
0
-1.02
-1
-0.98

The upshot



ΔE (Probed by Experiment)

The upshot



Fractional error $= \Delta_2$

ΔE (Probed by Experiment)

Numbers for evaluating $\boxed{\Delta_2 = \left(\left(\frac{E_0}{\Delta k} \right)^{\alpha} \frac{\Delta E}{E_0} \right)^2}$

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Cosmology?
Need gravity

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Some choices:

$$\boxed{\Delta k = m_\gamma = 10^{-25} GeV}$$

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$\boxed{\Delta E = E_{UHECR} = 10^{11} GeV}$

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$$E_0 = \rho R_H^3 = 10^{80} GeV$$

Some choices:

$$\Delta k = m_\gamma = 10^{-25} GeV \qquad \Delta E = E_{acc} = 10^3 GeV$$

$$\Delta k = H_0 = 10^{-42} GeV \qquad \underbrace{\Delta E = E_{UHECR} = 10^{11} GeV}$$

Careful: Looking for *field theory* effects.

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α	$\Delta k(GeV)$	$\Delta E(GeV)$	Δ_2
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1/2	10^{-42}	10^{3}	10^{-16}
1/2	10^{-42}	10^{11}	10^{-8}
3/4	10^{-25}	10^{3}	$10^{1.8}$
3/4	10^{-25}	10^{11}	$10^{9.8}$
3/4	10^{-42}	10^{3}	$10^{14.5}$
3/4	10^{-42}	10^{11}	$10^{22.5}$
1	10^{-25}	10^{3}	10^{28}
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1/2	10^{-42}	10^{11}	🟩 10^{-8}
3/4	10^{-25}	10^{3}	🟨 $10^{1.8}$
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small (good)

large (bad)

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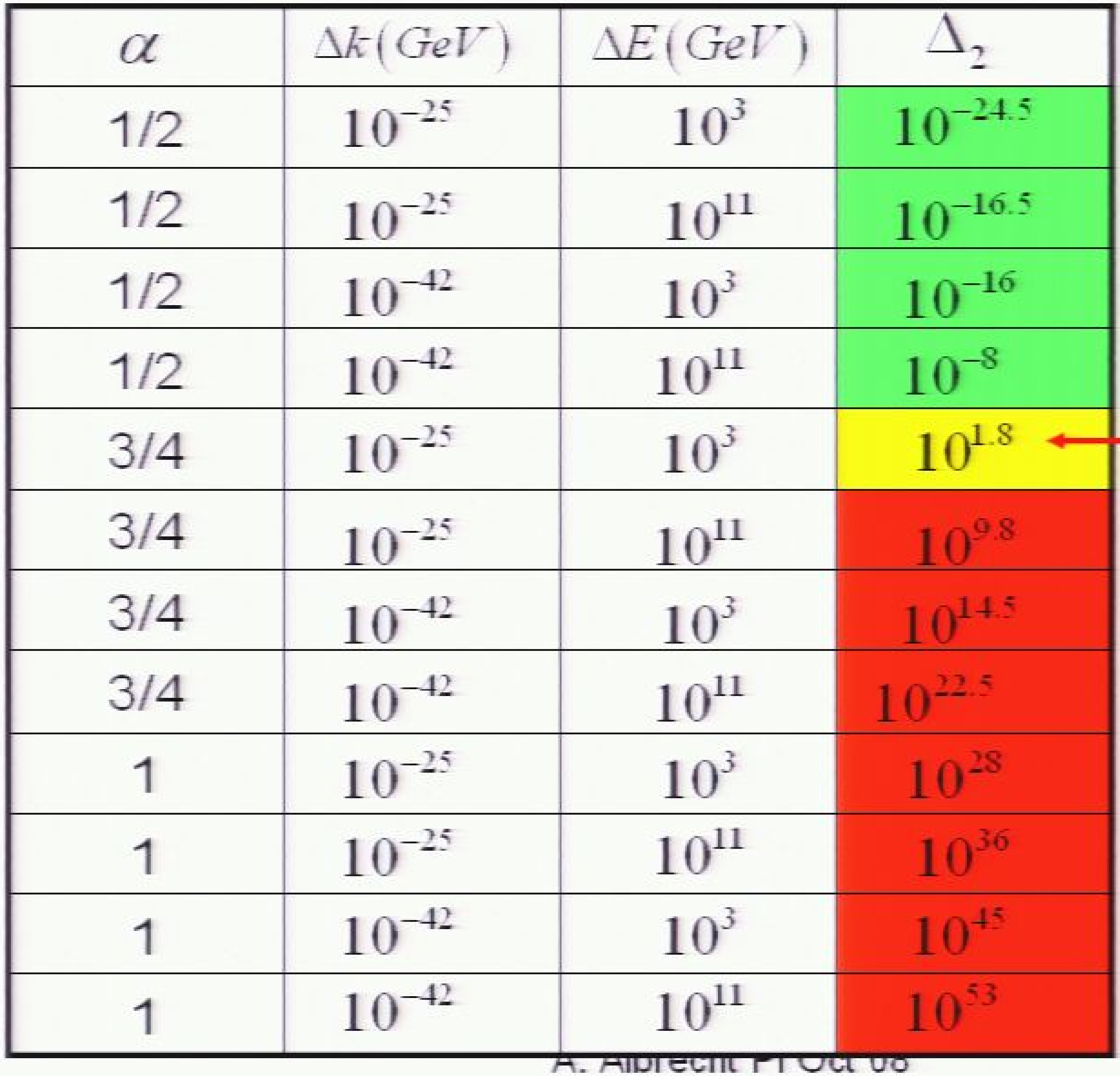

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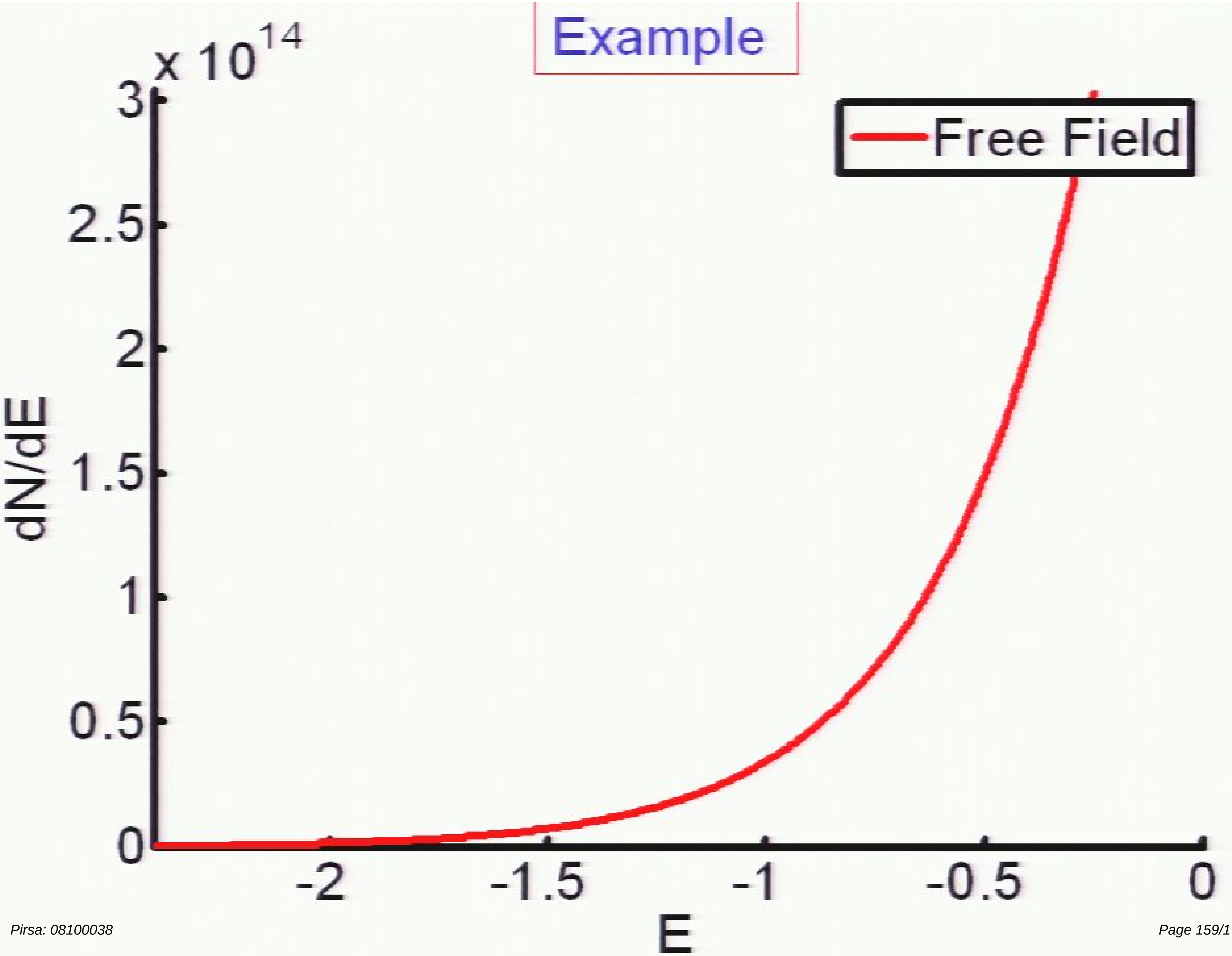
Expansion OK if $\alpha = 1/2$ $(3/4?)$

Example



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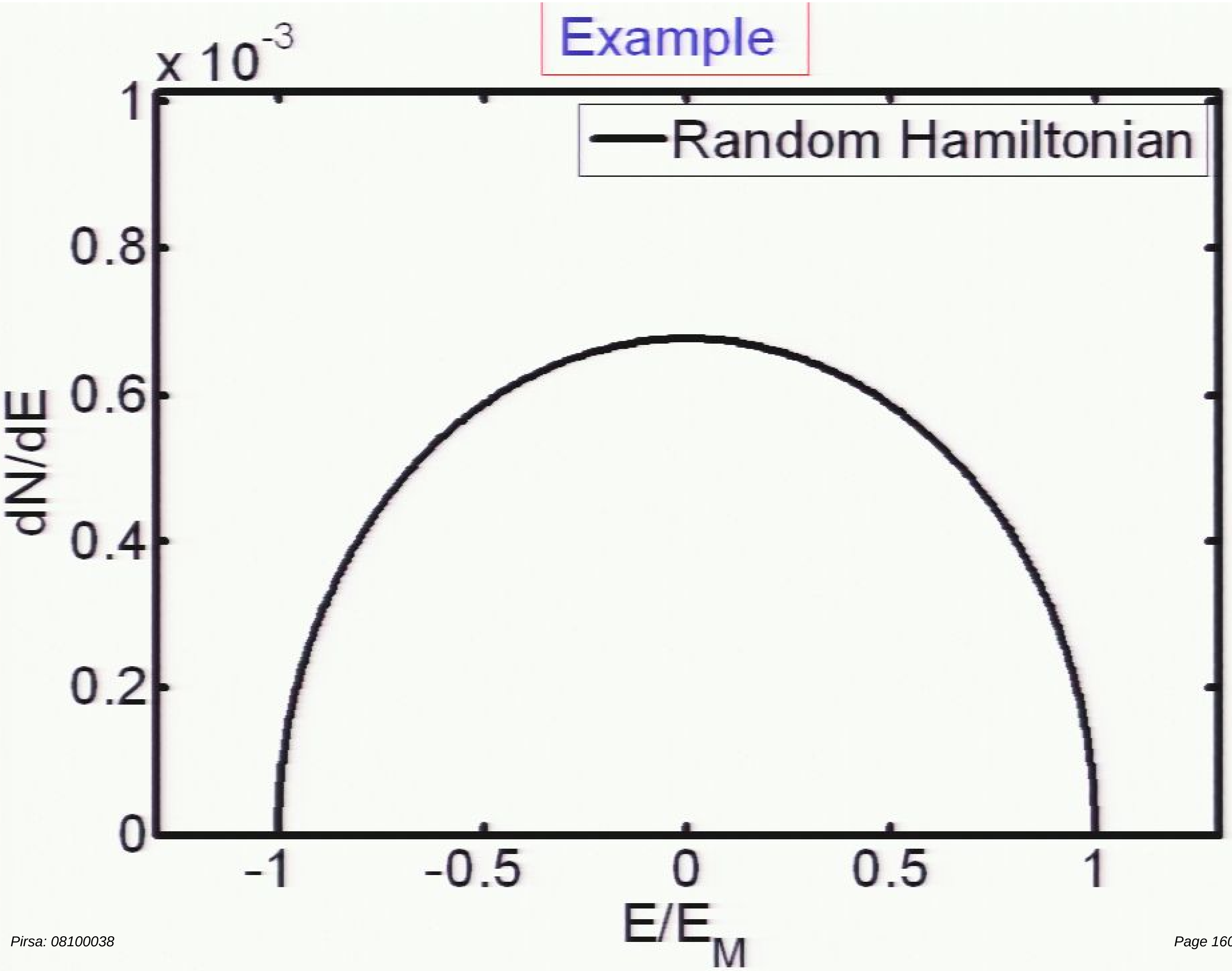

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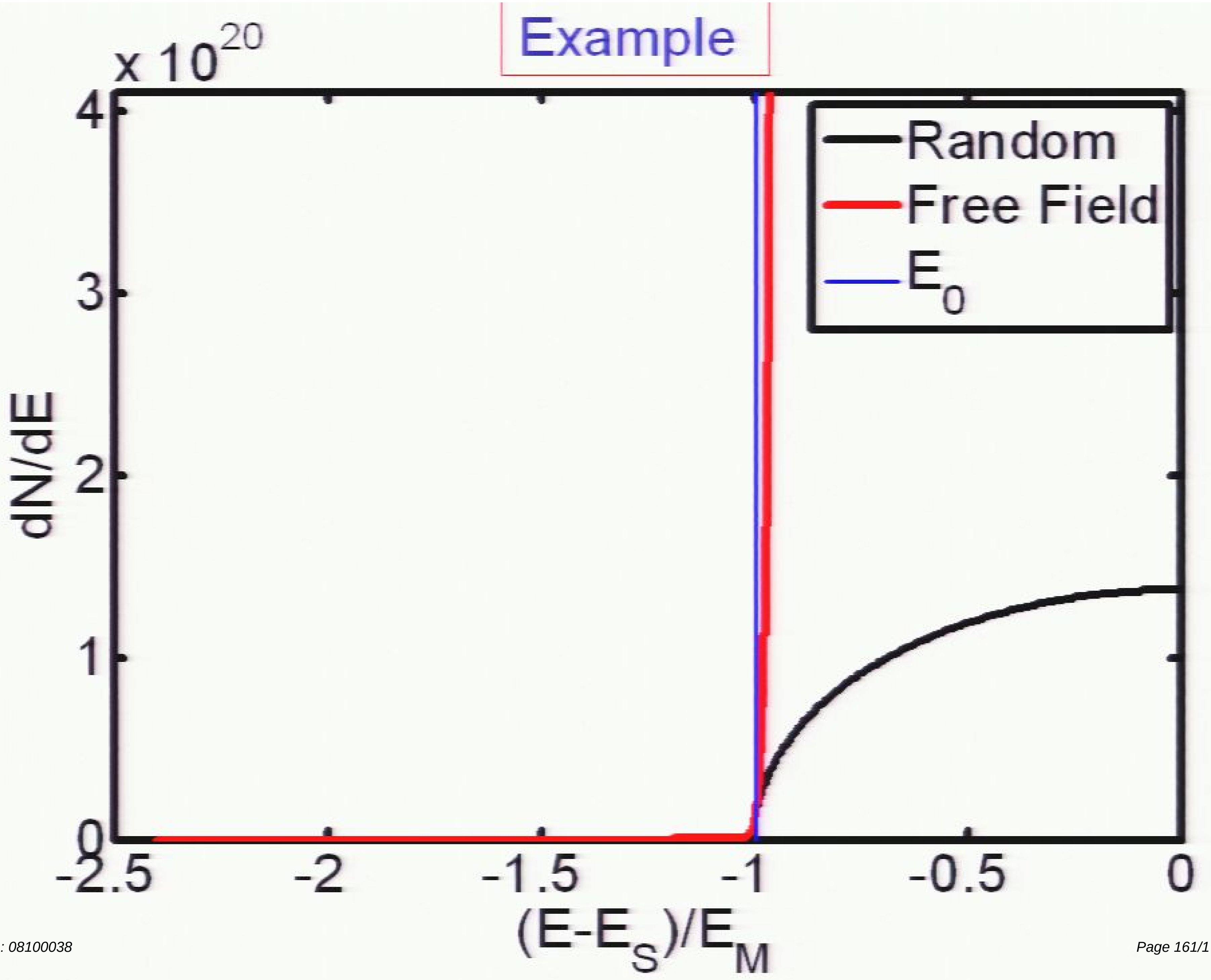

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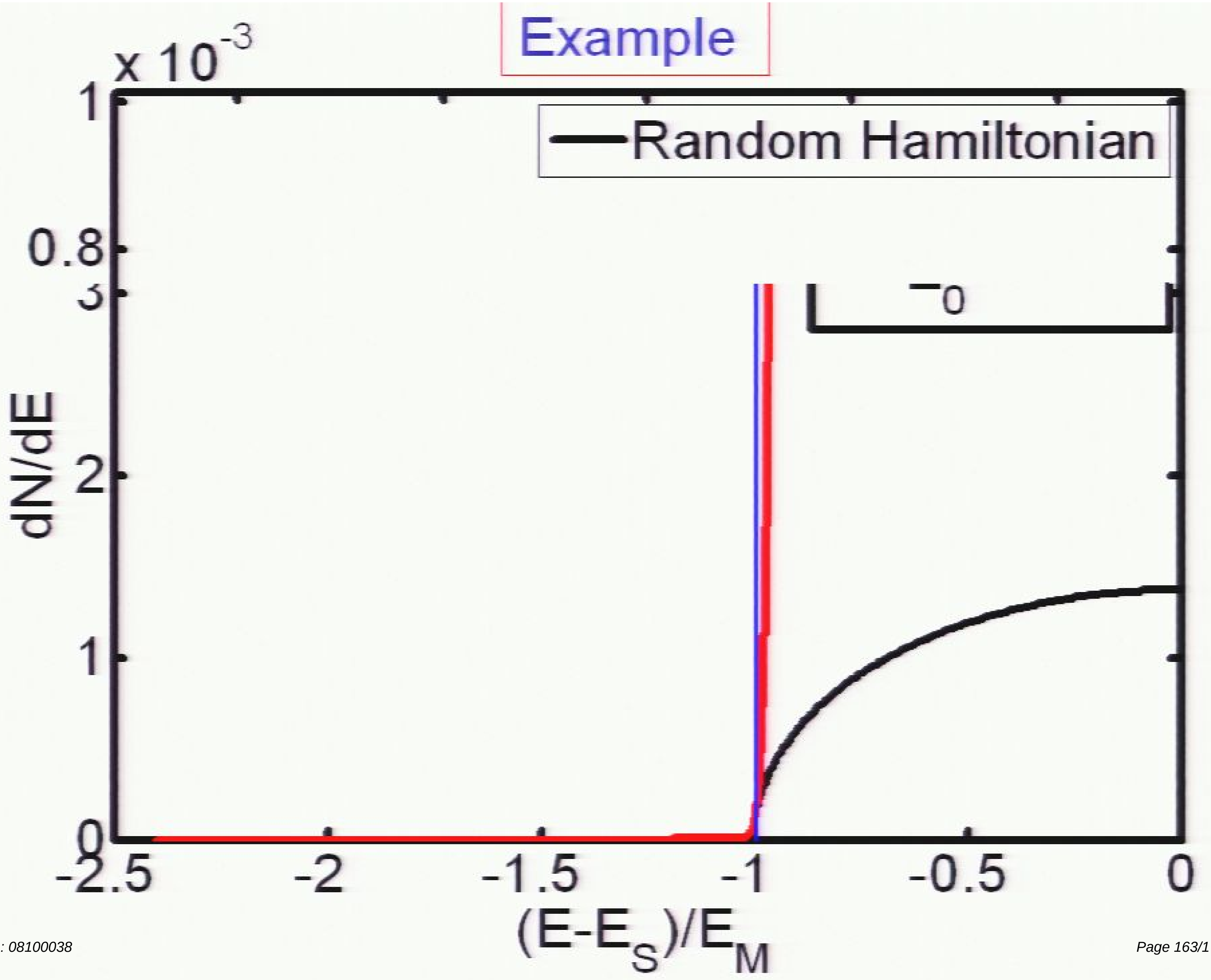

$E_0 = \rho$[illegible]

$$\Delta_2 = \left(\left(\frac{E_0}{\Delta k} \right)^{\alpha} \frac{\Delta E}{E_0} \right)^2$$

A source of
→ interactions?
→ deviations from field theory?
→cosmic structure?

[illegible]	[illegible]	[illegible]GeV)	Δ_2
1[illegible]	[illegible]	[illegible]0^3	10[illegible]4.5
1/[illegible]	[illegible]	10^{11}	$10^{-16.5}$
1/2	[illegible]	10^3	10^{-16}
1/2	[illegible]	10^{11}	10^{-8}
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small (good)

large (bad)

Additional thoughts:

- ➔ Poincare invariance

$$E^2 = p^2 + m^2$$

Additional thoughts:

- Poincare invariance

$$E^2 = p^2 + m^2 \xrightarrow{E \gg m} E = p$$

Additional thoughts:

- Poincare invariance

Additional thoughts:

AA & A. Iglesias arXiv:0805.4452

➔ Use thermodynamic estimates for components of the universe to study S and its derivatives

- S'' related to specific heat (related to curvature of dN/dE)
- Throw caution to the wind re gravity
- Apparent consistency through S'''

	Rad	DM	BH	Λ
S	10^{88}		10^{100}	10^{120}
S' (GeV^{-1})	10^{13}	10^{4}	10^{27}	10^{42}
S'' (GeV^{-2})	10^{-62}	$\pm 10^{-2} \sim 10^{-76}$	10^{-38}	10^{-40}
S''' extrapoltd.	10^{-142}	10^{-156}	10^{-118}	10^{-120}

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Watch for updated version (error in posted version related to this topic)

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➔ Arrow of time

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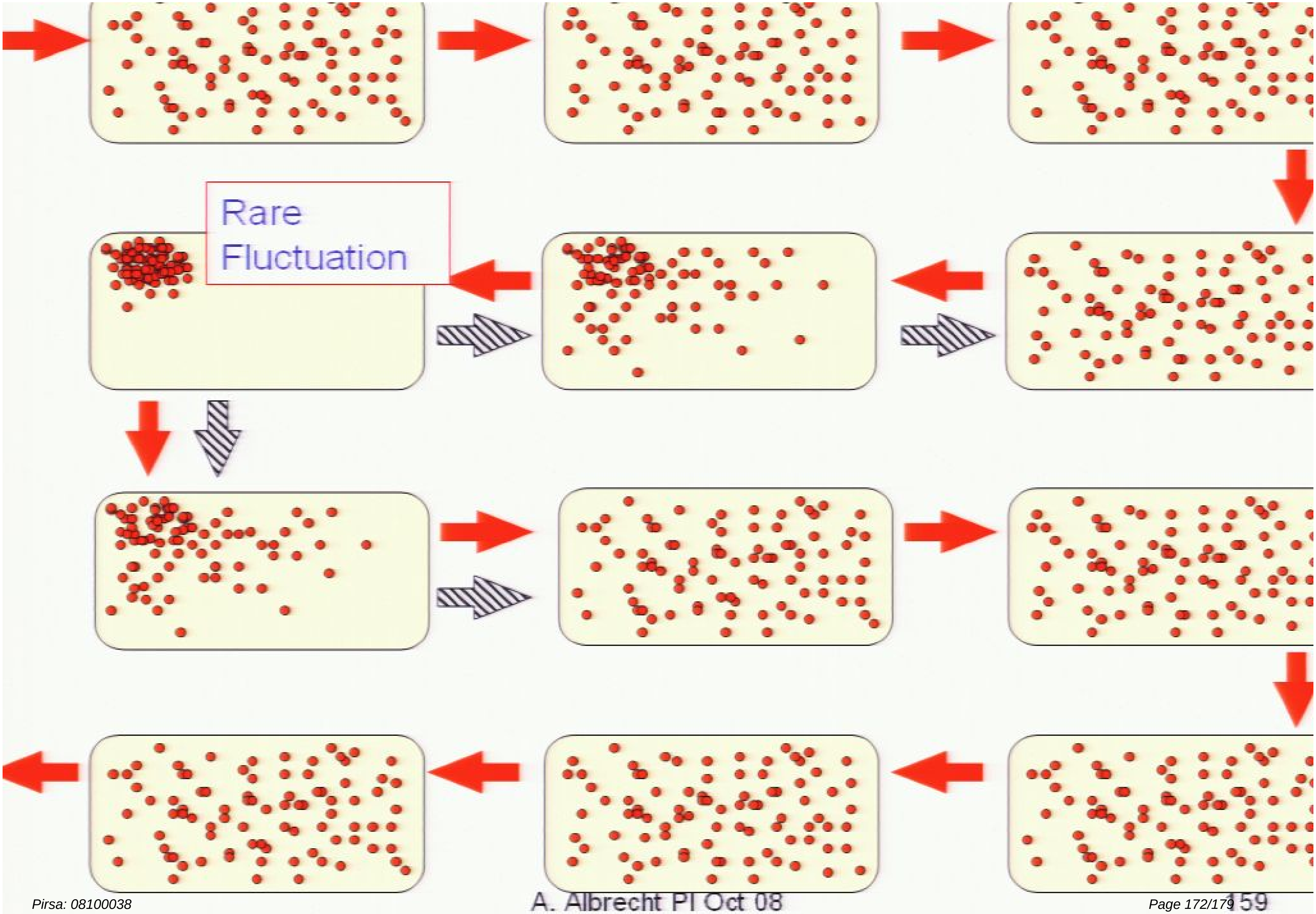
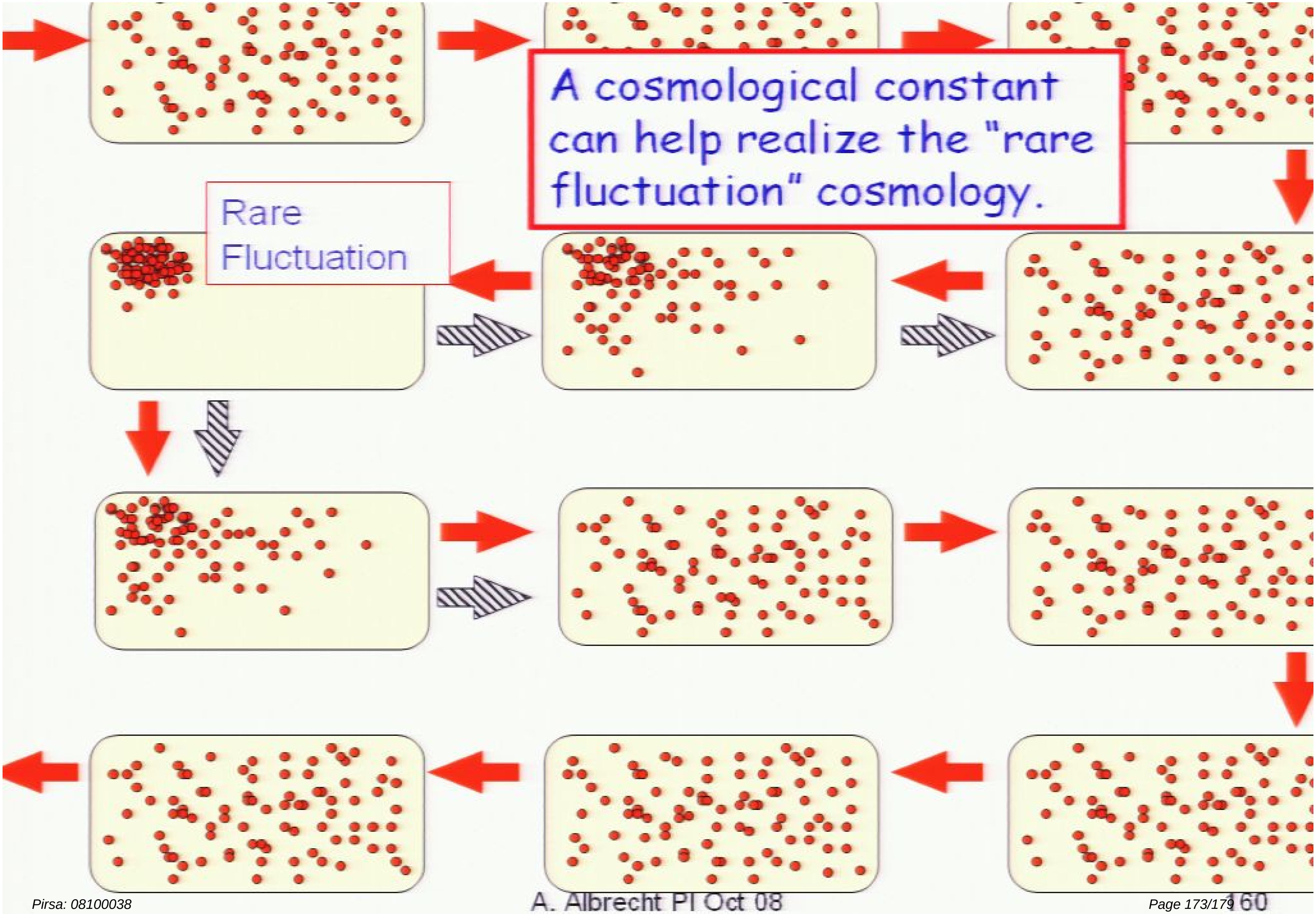
- I am very fond of the picture where cosmology is described by rare low entropy fluctuations from an equilibrium state. AA & Sorbo 200



Rare Fluctuation



A cosmological constant can help realize the "rare fluctuation" cosmology.

Conclusions

- Clock ambiguity threatens “physics as we know it”
- It may be possible to extract physics despite the clock ambiguity.
- It seems possible to find field theory (to a sufficient degree) in *any* sufficiently large random Hamiltonian (→ a prediction re optimizing separability)
- Time dependence of H OK
- Predictions of gauge theory and gravity possible
- Perhaps “random” is the most powerful foundation for fundamental physics (as I have long argued it is for “initial conditions”).

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Radical:
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critically
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VERY different form
"normal" (i.e. "ground
state" is pure fantasy)

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